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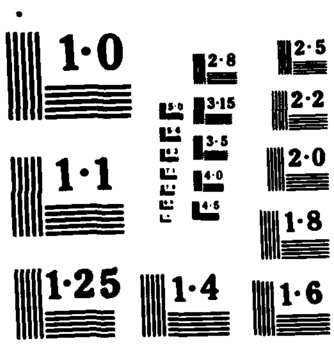

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WHY A NETWORK ENERGY MONITORING AND CONTROL SYSTEM?

AD-A162 932

BY

ROBERT B. BARRON

A REPORT PRESENTED TO THE GRADUATE COMMITTEE
OF THE DEPARTMENT OF CIVIL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

FALL 1985

ABSTRACT

The building owner has increasingly challenged the facility operator to reduce utility consumption. The operator can only do this by either controlling the type and level of service provided to the occupants, by improving the energy conversion process, by eliminating waste, or by controlling when and where building services are provided. The last offers the greatest reduction for the least cost.

The control can be as simple as instructing the building occupant to turn off equipment when not in use. If the occupant forgets to do this, a timeclock could be used to turn off the equipment on some predifined schedule. However, such simple schemes may not be adequate if the level of control is more complicated than this or if the operator must control a wide variety of equipment. By installing the control instructions in a computer and connecting it to each piece of equipment, ~~the~~ a building facility operator can use the computer to consistently implement the control strategies to utility consumption. This essentially is what is known as an Energy Monitoring and Control System (EMCS).

Typically, the building owner insists that the reduction in utility costs after the first few years exceeds, or "pays back", the installation cost of the EMCS. Due to the high cost of minicomputer equipment, early systems could only have one computor that was remoted through a communications network to many nearby buildings. However, inexpensive but capable microcomputers are available that can provide control for a single building. This report explores the desireability and cost of an EMCS system in general and of these two alternatives in particular. It is found that the quickest payback was found in systems implementing the fewest number of control strategies. Further, it appears that the choice of a network over a single building control system depends on the number of buildings connected.

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CHAPTER 1
INTRODUCTION

To the facility operator, the term Energy Monitoring and Control System (EMCS) connotes a promise that something can now be done about the consumption of energy. At its heart is the tool of the modern engineer: a computer. Tireless, the computer can constantly look for opportunities to save energy. Fussy, the computer can attend to the large number of detailed steps needed even for a small energy program. Freed of these tedious day-to-day tasks, the facility operator can effectively manage the energy program.

Many facility operators in the United States Navy believe that Energy Monitoring and Control Systems do not live up to this promise. Many systems did not work when built. Many systems took years to complete as they were modified to work with existing, frequently very old, buildings. The benefits derived from those systems that did work were less than the complete energy package expected. As a result, these operators are very reluctant to consider any future installation of the systems at their facilities. (5)

History

As mechanical and electrical systems in buildings grew in complexity, many operators started installing in the mechanical rooms monitoring boards for each major system or subsystem. The board would usually indicate graphically the physical layout of the system and the flowpaths or sequences of the system operation. On the board, sometimes superimposed on the graphics, would be various gauges or indicator lights each describing the status of some part of the system. For example, the temperature of the air at some point in a heating duct would be remoted to the board. The operator could then quickly understand the particular system and its operational status. The operator could even do some limited troubleshooting if the remote indicators were carefully selected.

The natural step after this was to operate the various valves, motor starters, and switches from the board. Each such device was simply connected to some remote control located on the board. In many cases, some of the interlocks and automatic controls were also moved from their system location to the board. Now the operator could monitor the status of the system, actively control it, and adjust the setpoints or logic of the automatic controls at one location. These boards are still being installed because of this savings in operator labor.

For large, complex buildings, sometimes these individual boards would be located in the same room. Either as a collection of boards or as one master board, this Central Supervisory Control System provided the operator with a complete view of the status of the various building systems. (1,pp.2 to 5)

Manufacturers introduced the infant computor technology to the facility operator first with programmable controllers. These devices replaced the pneumatic and electric devices that formed the hard-wired interlocks and automatic controls in the system boards described above. The programming language was written around the ladder diagram technique used for specifying the hard-wired controls, so these devices were readily accepted by the designers. These early (and some of the current) models used a very simple language, more like a series of letters or symbols, that required some training to manipulate. The operator in some cases only saw that the familiar hard-wired devices were now replaced by an unfriendly black box. (33,p.40)

When minicomputors dropped in price, many units were adapted or developed to replace the hard-wired controls of the Central Supervisory Control Systems. Since the size of

the memory of the minicomputor is much greater than that of the programmable controller, programming languages were made easier to understand. The relatively open architecture allowed a greater flexibility in software design, resulting in a wide variety of control schemes. Manufacturers harnessed the computor's ability to massage data in its memory and output reports by printer and cathode ray tube (CRT) screen to eliminate the board filled with graphics and indicators. The operator now only had to input the description of the information desired and the computor would output pertinent information and the answer, either a status or some sort of report. The manufacturers then used multiplexing techniques to replace the individual wires going to each sensor and control with one wire. The Energy Monitoring and Control System was born. (4)

Computor technology has progressed to the point where the capability of some microcomputors equals or exceeds that of the old minicomputors. Manufacturers now offer microcomputor units that have much of the same variety of control schemes but at a fraction of the cost of the minicomputor. The understandability of the program language, the variety of outputs, and the number of sensors and controls supported have passed that of some of the older minicomputors and is rapidly increasing. Since the

number of sensors and controls has been limited, these units have generally been installed one per building. The units are called Single Building Energy Monitoring and Control Systems (SBEMCS). In this report they will be referred to as Single Building Control Units. (34,p.1)

Problem Statement

Due to the high cost of the minicomputor hardware, Energy Monitoring and Control Systems could not be installed for just one building (unless it was a very complex building such as a hospital). The minicomputor was therefore located somewhere in the vicinity of many buildings. The sensors and controls in each of the buildings were remoted to the minicomputor through a network of communication links. The entire system had to be built at the same time so that the savings from the control schemes would be large enough to justify the initial expense of the minicomputor and the network.

However, now the cost of a Single Building Control Unit is low and it has advanced capabilities. The savings from the control schemes from just one building can justify the expense of one such unit. Each building can have its own unit, with no network. There is no need to install all the units at the same time.

Report Objective

This research effort explores the various decisions that could be made by the operator in developing a program to automate the monitoring and control of energy consumption. The rationale for the networked Energy Monitoring and Control System will be compared to that for the non-networked collection of Single Building Control Units.

The viewpoint is how the facility operator will select the program, not how the constructor will install it.

CHAPTER 2
ENERGY CONSUMPTION

Energy enters a building in the guise of electricity, oil, natural gas, steam, and other such utilities or commodities. Approximately half of this energy is used to provide lighting to the occupants. Another thirty percent is used for heating, ventilating, and air conditioning (HVAC). The balance is used in the operation of the process equipment installed in the building by the occupants. A small percentage of the incoming utilites is wasted through leaks in the building distribution systems. These figures are annual totals for typical office buildings observed by the author during his career. While the numbers may be different for different buildings and climates, the same categories of service are provided to the occupants.

The occupants consume the energy, not the building. The facility operator manipulates the incoming utilities to provide the services required by the occupants. However, as the cost of the utilites has rapidly risen since the oil crisis of 1973, the facility operator is increasingly challenged to reduce the building's intake while maintaining the same level of service or comfort. In developing a program to do this, the facility operator must

first define what he controls and what the occupant controls.

Types of Control Exercised by the Facility Operator

The facility operator has little control on what type of services are to be provided. The reason the building exists is to provide lighting for tasks, heat for comfort, and so on. The building owner has decided that these services are to be provided to the occupant, and the occupant defines the level of service to accomplish the task assigned by the building owner.

Waste in the distribution system can be controlled by the facility operator.

The operator controls the process that converts the energy into light, heat, or other service. The process that was designed into the building is sometimes less efficient than another that is now available. In some cases, however, changing the process would be more expensive than can be justified by the resulting savings in utility cost. For example, an existing lighting fixture converts electricity to light (which is used by the occupant) and also converts electricity to heat (which is not normally used by the occupant). Another light fixture

may be available that uses less electricity, produces the same level of light, and sheds less heat. However, the installed fixture is still in good condition. Replacing the fixture is probably not cost effective unless the value of the electricity not used is greater than the cost of the new fixture. If the annual avoided cost of electricity equals the cost of the new fixture, the decision to replace the fixture is said to have a payback of one year. While altruistic motives of reducing the use of natural resources may enter into the decision, this measurement of economic payback is by far the one most used to evaluate alternative actions in an energy program. The facility operator has control over the conversion process only if the cost of modifying the process is justified by its payback.

The facility operator can control when the energy is used. For example, electricity used by light fixtures can be turned off when the service (lighting) is not needed by the occupants (such as when the building is vacant), or the service is provided by some other means (such as by sunlight through the windows). This control must reliably react to the changes in the needs of the occupant.

Last, the facility operator can control where the service is provided. Providing a light switch at each work

station increases the time the light fixture is off compared to the time if only a single switch was provided for the entire room. The control must reflect how the occupant uses the space.

Controlling Building Services

The facility operator applies these five types of controls by installing appropriate mechanical and electrical systems. Since each building is unique, each building has to be evaluated individually to determine what systems are appropriate. The physical form of each system will depend on the design of the existing building systems. The level of control the systems provide depend on how well they react to the occupants' needs.

Lighting

Two types of lighting are usually provided: task and general. Task lighting is concentrated on the work surface for use by one person and is usually provided by a desklamp. General lighting provides a uniform level of illumination over an entire room and is usually provided by fixtures mounted on or near the ceiling. Most building designs provide the illumination required for the work surface using general lighting, eliminating the need for task lighting. A few rely on task lighting for the work surface and provide a minimum general illumination that

allows movement around the room and prevents the feeling of living in a cave. Some buildings are designed to allow daylight to provide the illumination but most buildings rely exclusively on electric light fixtures.

Lighting has to be provided throughout the interior of the building as well as for certain purposes on the exterior. The facility operator can typically prevent the waste of lighting by keeping the fixtures and diffusers clean (and the windows clean for daylighting). The fixture could be replaced by one that converts electricity to light more efficiently.

The simple light switch is the best tool the facility operator has to control when the light is used and where it is used. A switch at the entrance to an office is convenient for the occupant to turn on when entering and turn off when vacating. For a twenty-person office, though, some sort of awareness training must also be given to the occupants so that the last person vacating turns off the lighting. One other option in this case would be to task, say, a security guard to turn off the lighting at some set time after normal working hours. This sort of control could be automated with a time clock, and the readily accessable switch removed. For this same office,

the facility operator could install additional switches so that the lighting is zoned. If the zones matched individual or groups of workstations, then certain of the occupants could be tasked to turn off their respective lighting. The advantage is the increased likelihood that the lighting will be turned off at quitting time, while with the security guard they may be scheduled to be turned off one hour after quitting. By tasking the security guard (or installing the time clock), the facility operator hopes to avoid purchasing the electricity that had been used by lighting left on all night. If instead, several more switches were installed, the facility operator will, in addition to not purchasing the electricity for lights left on all night, avoid the cost of leaving the lights on for one hour after quitting time. Note that the facility operator has to make many judgements based on his experience with the occupants. For example, how many times and by how long will the security guard be late? The facility operator can then total the costs (of the security guard, light switches, or training) and total the avoided purchases of electrictiy to determine the economic payback for each idea. Appropriate ideas could then be made part of the energy program. (40,pp.5-1 to 17-39)

Some lighting in the building could be turned on at night for security and for janitorial personnel. This will affect the estimated reduction in energy consumption. For the remainder of this report, it will be asummed that building services are not required at night. This maximizes the potential energy reductions.

Most lighting is controlled best by the simple switch. The person operating the switch can easily decide if the lighting is needed, and the switch is convenient for the occupant. Lighting whose need can be defined by some schedule, such as nightime security lighting or classroom lighting, can be controlled by some central system. Therefore, despite its large share of the total energy consumed in the building, typically very few lighting systems will be connected to an Energy Monitoring and Control System.

Process Equipment

Most process equipment have their own controls. Generally, a single person is tasked to operate the equipment. The facility operator can usually train the equipment operators to turn off their process equipment when not needed. In some cases the Energy Monitoring and Control System can be connected to the process equipment to

provide central control not provided by the process controls, or to prevent building services (such as lighting) from being turned off by the central control when the process equipment is still in use.

Heating, Ventilating, and Air Conditioning

The goal of this service is to create an appropriate conditioned environment inside the building. This environment will, as a minimum, provide conditions for the proper operation of the process equipment. The level of service will often be above this minimum so as to provide some comfort for the occupants as a means to increase productivity. For example, a microcomputor word processor may function well with the room air at a temperature of 50 degrees Fahrenheit, but the clerk will want to wear gloves and a light coat. By raising the temperature to 65 degrees, the clerk will usually not need to wear gloves nor a coat. The clerk can type more accurately without wearing gloves, and will enjoy the workplace more without wearing a coat. The improvement in productivity may justify the increase in the cost of utilities to raise the temperature. How much the temperature is to be raised depends on the tasks the occupants perform and on what the occupants have grown to expect. This service will be provided by several building subsystems.

Heating

The heating subsystem will raise the temperature and lower the relative humidity of the air inside the building. Heat will then flow from the process equipment and the building surfaces to the occupant. As the temperature of the air is increased, there is less chance that the occupant will feel chilly from the heat conducted from the body (at 98 degrees) to the air. However, the same result can occur if the heating subsystem directly raised the temperature of the building surfaces. Heat will flow from the warm surface to the process equipment and to the body by radiation. Therefore, the temperature of the air can usually be lower for an equivalent occupant comfort. Heating subsystems can therefore be categorized as either an air type or a radiation type.

The air type of system draws air from the room, raises its temperature in a heat exchanger, and then distributes the warm air through ducts and diffusers. The newly introduced air mixes with the cooler air in the room and eventually an equilibrium temperature is reached that is higher than at the start. As the equilibrium temperature reaches the desired room temperature, there are three methods to terminate or adjust the effect of the newly introduced air on the room temperature.

The first is to simply turn off the heating subsystem. This is typical for residential applications. The occupants in a commercial building usually object to the distraction of the air flow starting and stopping.

The second is to reduce the temperature of the air supplied by the heating system. At full capacity, the air may be supplied to the room at 110 degrees Fahrenheit. As the room air approaches the desired temperature of 65 degrees, the air supplied to the room may be reduced to 80 degrees. The diffusers must be located so that the air does not blow directly on the occupants since the air at 80 degrees will feel cold compared to the body temperature of 98 degrees. This alone could prevent the facility operator from converting an air system to this method of control.

The third method is to vary the volume of the air supplied to the room by the diffusers. A small quantity of air, even at 110 degrees, will not raise the equilibrium temperature much when mixed with the much larger quantity of room air. The diffusers must be located to provide an even distribution even at the lower quantity (and hence lower throw velocity) to prevent hot and cold spots. (38,pp.32 to 37)

A radiation type of heating system raises the temperature of some surface in the room sufficient to radiate heat over the distance to the occupant or equipment to be warmed. A classic example is a system of hot water or steam radiators. The radiating surfaces must be distributed to provide uniform radiation despite obstacles created by equipment, furniture and the occupants. The primary method of control is on/off. Varying the surface temperature is usually impractical since reducing the temperature reduces the effective distance, possibly creating hot and cold spots.

Ventilation

The goal of ventilation is to remove odors, contaminates, and otherwise stale air from the inside of the building. Typically this is accomplished by forcing a small amount of outside air into the building. This air will displace its volume of air already in the building. The displaced air exits to the outside through dampers or through cracks and imperfections in the building structure. Over a relatively short period of time, usually measured as an hour, the volume of outside air introduced will equal some multiple of the room air volume. Dampers to the outside are usually incorporated into the ductwork of air

type heating and cooling subsystems, and the ventilation air is mixed with the recirculated room air and moved by the same fan.

More energy is consumed in changing the outside air temperature to the desired temperature than is consumed in recirculating the room air. Therefore, the amount of ventilation air should be kept to the minimum required for the type of occupancy. On the other hand, a major objection to turning the heating or cooling subsystem off to control the room temperature is that this may reduce the quantity of ventilation air below the minimum for health. Also, changes in the type of occupancy may increase the need for ventilation air or provide an opportunity to reduce the existing quantity provided.

Air Conditioning

The goal of an air conditioning subsystem is to maintain the temperature of the air in the room at some comfort level and at the same time maintain the moisture content of the air (usually expressed as relative humidity) at some level. Since the body sheds heat generated by exertion primarily by moisture, a person will not feel hot if the air is maintained at a temperature below the body temperature and has the capablility of absorbing moisture.

Process equipment may have parts that are cool enough that the moisture from a high humidity air will condense, probably damaging the parts. (30)

The subsystem draws air from the room, lowers its temperature so much that some of the moisture condenses, and distributes the air to the room through diffusers. This small quantity of cold, dry air mixes with the large quantity of warm, wet air in the room until an equilibrium mixture of cool air with a low moisture content is reached. The technique is similar to the one used in the heating subsystem, but the problem is complicated by having to consider the level of moisture.

The three methods of controlling the room air are the same as for the air type heating system: on/off; vary the temperature; or vary the quantity of the air delivered to the room. The objections to each are similar to those described for the heating but with a difference. The main objection to turning the subsystem off is that the circulation of air within the room is disrupted, possibly creating spots with high humidity. For the method of varying the temperature, the designer is severely constrained by the need to drop the air temperature very

low to condense enough moisture from the air. Designs that vary the quantity of air must have diffusers designed to still evenly mix the room air.

The Energy Audit

Evaluating the potential for reducing the energy consumption is complicated. The evaluator must determine how well the installed building systems work, understand the constraints and needs of the occupants, and project the consumption of energy by the existing and alternative systems. This effort is called the energy audit of the building.

The audit is hampered by poor data. Noone can give a figure of the percent of the occupants who feel a chill, and be less productive, if the temperature from the heating diffuser is so many degrees less than body temperature. As-built drawings do not show how the occupants use the room. Historical meter data on utilities may not be available or may not be sufficiently detailed so that the effects of weather or occupancy can be deduced. The evaluator must get to know the building and use experience and judgement in the process.

Presentation of the alternatives is hampered by their interrelationships. For example, reducing the heat shed by the lighting fixtures may, during the winter, upset the estimated use of utilities by the heating system. Various nomographs and cookbook calculations have been published, but the numbers are not valid unless the unique conditions surrounding the building have been evaluated.

Since so much of the preparation of an energy audit is not based on hard data, the day-to-day experience and judgement of the facility operator is frequently more valuable than the results of the audit calculations in developing an energy program. (31,pp.21 to 38)

CHAPTER 3
THE SCENARIO

With the completed energy audit, the facilty operator has a description of the existing building systems and a list of alternatives that are expected to reduce the consumption of energy. Many of the alternatives will be to replace a subsystem with one more efficient in converting the utility to the service. Some will call for modification or repair of existing subsystems to reduce waste. Third, many of the proposals will be to increase the facility operator's control of when or where the service is used. Within this third group are the alternatives that could be implemented by the installation of an Energy Monitoring and Control System.

The facility operator must now decide what would be the best configuration of an Energy Monitoring and Control System.

To illustrate this decision, numbers from a set of sample energy audit calculations will be used in the next several chapters. The sample was obtained from a Naval Civil Engineering Laboratory publication entitled Standardized EMCS Energy Savings Calculations (7). This publication presents a set of equations to calculate the

possible reduction in energy consumption if certain control strategies are implemented. The calculations used are reproduced as appendix A.

Description of the Building Subsystem Studied

The audit results are for one of the heating, ventilating, and air conditioning systems in a hypothetical office building located in Springfield, Missouri. The system draws air (return air) from 3000 square feet of office area and from outside (outside air) for ventilation. The air is cooled and its moisture is condensed during the summer by passing through a cooling coil. This air (supply air) is forced by a fan through ductwork to the room. Just outside the room, the air passes through a heating coil (reheat coil). During the winter, this coil will raise the temperature of the air to the desired diffuser temperature. During the summer, the air will be warmed to some minimum temperature to prevent drafts that could be caused by the dry, cold air from the cooling coil.

An air-cooled chiller provides the refrigerant for this cooling coil as well as for the cooling coils for two other systems in the building. An existing control on the air handling unit senses the temperature of the supply air and

adjusts the the cooling coil valve. By changing the opening in the valve, the flow of refrigerant is increased or decreased, changing the temperature of the coil, and thereby changing the temperature of the supply air leaving the coil.

The thermostat is another local control. It opens and closes the reheat coil valve in response to room temperature.

The fan runs continuously. The room air temperature is controlled by changing the temperature of the air entering the room.

The occupants are performing administrative tasks from 0730 to 1630 weekdays. There are no security or janitorial personnel in the building outside of these hours.

A designer today will rarely specify a system that uses reheat. For an average office space it consumes more energy than other equally acceptable systems. Reheat is still used when heating and cooling loads vary widely among the rooms served by a single air handler. For example, such variations could be caused by uneven solar heating.

This system is used here since it demonstrates a wide variety of control alternatives. However, since it is so inefficient at the start, the reheat system will have large energy reductions from the application of an Energy Monitoring and Control System.

Cost information

All costs and savings are expressed as of the end of calendar year 1981. This research effort uses these numbers to illustrate the decision process in comparing one alternative to another. The relationship between the numbers is therefore more important than absolutely correct figures.

The material and labor costs for the various components of an Energy Monitoring and Control System were taken from the Naval Civil Engineering Laboratory's publication EMCS Cost Estimating Data (6). These costs are as of December, 1981. Using this single source ensures that the relation between costs is accurate, since the same estimating assumptions would have gone into all of the numbers.

Material costs of the Stand Alone Units were taken as averages of the quotes reported in the survey included in

the Naval Civil Engineering Laboratory's publication <u>Controlling Energy Consumption in Single Buildings</u> (33). The quotes were as of August, 1981.

Since 1981 the costs of the solid state and computor devices have dropped, while the cost of labor has increased. An installation of equipment of similar capability probably will be less expensive today compared to 1981. Therefore, the economic paybacks presented in this report (avoided energy cost divided by installation cost) are probably conservative.

The costs of electricity and fuel oil are based on national averages for the end of August, 1981 as reported by the periodical <u>Energy User's News</u> in the issue of 30 September, 1985. (14)

CHAPTER 4
CONTROL STRATEGIES

Various techniques and procedures to control the air handling unit have been classified and given titles by engineers implementing Energy Monitoring and Control Systems. Each represents a strategy for reducing the consumption of energy. The person preparing the evaluation can use these definitions to organize the results of the calculations. Using a checklist of all defined strategies will possibly prevent the evaluator from overlooking an alternative. Use of the common terminology will speed consultation with other engineers during the evaluation process, shorten the specification used to buy the equipment, clarify the requirements of the contract for the installer, and allow standard training packages to be developed for the operators. (11; 12; 13,pp.3-2 to 3-11; 21)

Evaluate Each Strategy Individually

Each control strategy involves the control of one or several components of the air handling unit. However, the result is that it affects the whole system. The strategies must be defined so that the results of one strategy must not negate or affect the results from implementing another. The strategies must be independent of each other: the

amount of avoided energy cannot be counted twice. This allows the evaluator to compare each strategy as an alternative, with the option of mixing several strategies into a package. For convenience in this report, each strategy will be given a single letter designation.

Scheduled Start/Stop (Strategy A)

This strategy is simply turning the air handling unit off when not needed. Since the office space in the scenario is occupied only from 0730 to 1630, weekdays, the air handling unit can be shut off from 1630 to 0530. The unit is turned on at 0530 to allow plenty of time to return the room air temperature to the desired setpoint before occupancy. To implement this strategy, a relay must be installed in series with the fan motor circuit that, when the relay is energized, would turn off the motor. The relay coil is remoted to some point in the building where it is connected to some sort of control panel (the control panel is selected in the next chapter). The control panel will remember the desired schedule and energize the relay.

A second relay is placed on the chilled water pump. Since this will secure the refrigerant to all three air handling units in the building, for simplicity it will be assumed that all three air handling units can be turned off

using the same schedule. Naturally, since only one relay needs to be installed on the chilled water pump, the air handling units can share it. For comparing alternatives in this report, only a portion of the cost of the relay for the chilled water pump will be charged to this strategy.

The evaluator could have found that the occupants could turn off the equipment themselves at the end of the day, and restart it in the morning. However, due to human error and forgetfulness the unit was not turned off every night. Also, there is the undesireable result that the room temperature is not at the desired setpoint at the start of the day. Installing an Energy Monitoring and Control System to implement this strategy will: (1) reduce consumption <u>only</u> by the energy used for the nights the unit was left on; and (2) increase the consumption for the warm-up period two hours before occupancy. For this report, it will be assumed that no existing efforts are being made to conserve energy, therefore the full amount of the calculated reduction in consumption will be credited to the proposed Energy Monitoring and Control System.

<u>Optimum Start/Stop (Strategy B)</u>

This strategy turns off the air handling unit when the room is unoccupied, the same as if scheduled start/stop (strategy A) was used. However, rather than restarting the

air handling unit two hours before occupancy, the optimum start/stop strategy adjusts the warm-up period based on the outside air temperature and the room temperature before startup. This strategy requires that a sensor be located in the room to report the room air temperature to the control panel, and another sensor for the outside air. Two relays are still required, one for the fan motor and one for the chilled water pump. To keep these two strategies independent, this strategy will be credited only with the difference between the two hour warm-up and the optimized restart.

An initial estimate is given to the control panel of the thermal inertia of the building and the capacity of the air handling unit to increase or decrease the room air temperature per unit of time. The control panel will use these and the values from the temperature sensors to predict a warm-up time. A more elaborate algorithm will record how long the room actually needed to warm up, compare that to the predicted time, and adjust the estimate.

The air handling equipment could also be turned off before the occupants leave the building, allowing the room temperature to coast upward or downward. An estimate of by

how much the occupants will change the room temperature over a unit of time must be added to the algorithm. Also, the fan may have to remain on to provide fresh air ventilation for the occupants. For this report, the reduction in energy consumption from optimized shutdown is not included.

Ventilation and Recirculation (Strategy C)

Most air handling systems allow a fixed percentage of outside air to be mixed with the recirculated air for ventilation. During the warm-up period for the start/stop strategies, such ventilation is not needed since the building is unoccupied. In winter, if the outside air is colder than the room air before the air handling unit is turned on, the percent of that outside air drawn in must also be heated during warm-up. If the outside air is warmer, that air should be drawn in to warm the room air. For example, if the outside air temperature in the morning is 60 degrees and the room air is 55 degrees because the temperature outside dropped to 50 degrees that night, the outside air can be used to raise the temperature from 55 to 60 degrees. Then the outside air damper can be closed, and the heating coil used to raise the temperature from 60 degrees to 65 degrees.

This strategy requires a sensor for the outside air temperature and a sensor reporting the position of the damper. When the control panel is told by the start/stop strategies that the air handling unit is in the warm-up period, the control panel will adjust the outside air damper to either exclude the outside air or allow it to enter the room. During periods that the building is occupied, this strategy sets the dampers to the position for ventilation.

Day/Night Setback (Strategy D)

If certain process equipment required some minimum room air temperature even when the building is unoccupied, then the air handling unit probably cannot be turned off. For example, a piece of computor equipment that is left on overnight may need a room temperature not greater than 85 degrees, but if the air handling unit is turned off the temperature may rise to 90 degrees. Using the day/night strategy, during unoccupied hours the thermostat setpoint for the airhandling unit will be changed (set back) from 78 degrees to 85 degrees. A similar action would be taken for winter. In addition, the outside air dampers will be closed since the process equipment usually does not require ventilation.

If the building in this scenario had this situation, this strategy would be used instead of the combination of start/stop (A or B) and ventilation and recirculation (C).

Economizer (Strategy E)

When the ventilation and recirculation strategy (C) is used during the periods that the building is occupied, the strategy changes its name. In the summer, when the outside air temperature is lower than the room air temperature, the the outside air can be used to lower the room air temperature to the desired setpoint. When the outside air temperature is higher, the strategy closes the dampers to the position for ventilation (in the ventilation and recirculation strategy the dampers would be closed). Unfortunately, the calculation of the energy consumption avoided requires an hour by hour simulation of the outside air temperatures, occupancy, and inside air temperatures. Since this simulation is expensive, it was not performed. This strategy will not be considered for this scenario.

Enthalpy (Strategy F)

This is similar to the ecomomizer strategy (E). Here the strategy includes consideration of the humidities of the outside and room air. In some climates, the outside air may be cooler than the room temperature, but often will have a moisture content higher than the setpoint. Drawing

such air into the room will reduce the consumption of energy for cooling the air, but will increase the consumption of energy to remove the moisture introduced.

The calculation of the reduction of energy requires an hour-by-hour simulation of the temperature and the humidity. Since this simulation is expensive, this strategy will not be considered for this building.

Outside Air Limit Shutoff (Strategy G)

In this strategy, the air handling unit is turned off during periods the building is occupied when the outside air temperature is above some setpoint. If the inside temperature setpoint is 78 degrees for cooling, the air handling unit would be turned off if the outside air temperature fell below 75 degrees. The 3 degree difference, or rise, roughly adjusts for the heating of the room air by the occupants. This strategy assumes that the inside temperature quickly changes with changes in the outside temperature, which is common with poorly insulated buildings. Also, the building must have windows that open or some other way to provide ventilation.

Reheat Coil Reset (Strategy H)

This strategy raises the temperature of the cooling coil (warmer) until the supply air is raised so that the reheat coil can be turned off. If the cooling coil is left

at a constant temperature, energy is consumed to lower the temperature of the air (at the cooling coil) and then to raise its temperature (at the heating coil). This strategy reduces this duplication. However, since the cooling coil also removes moisture from the air, the coil should not be allowed to be reset so high that the room air will not be maintained at the desired level of humidity.

The control panel raises the temperature of the cooling coil by closing the cooling coil valve until: (1) the sensor on the reheat coil valve reports that the valve has closed; or (2) the upper temperature for humidity control has been reached. The cooling coil temperature is lowered if the sensor for the room air temperature reports that the room air is too warm.

Chilled Water Reset (Strategy I)

The cooling coil temperature can be raised either by closing the cooling coil valve or by raising the temperature of the refrigerant (chilled water). The energy consumed by a chiller is lowered when the temperature of the input water is lowered or the output water is raised. This strategy raises the output chilled water temperature to match the temperature required by the air handling unit. The control panel measures this indirectly by the

position of the cooling coil valve. When the valve is partially closed, the air handling unit is raising the temperature of the cooling coil. Therefore, the control panel raises the temperature of the chilled water until: (1) the cooling coil valve is completely open; or (2) the maximum allowable temperature allowed by the chiller manufacturer is reached. The chilled water temperature is lowered when the sensor for the room air temperature reports that the air is too warm.

Since there are three cooling coils served by the chiller in the scenario, the chilled water temperature will be raised until one of the cooling coil valves is wide open. The calculated reduction in energy consumption is divided among the three air handling units.

Duty Cycle (Strategy J)

This strategy takes advantage of the oversizing of the air handling unit. The air handling unit is sized for a peak load, which occurs infrequently. For the rest of the time, the unit could be shut down ten to fifteen minutes out of the hour and still maintain the desired room temperature. The same quantitiy of heat and moisture must be removed from the room air, but the fan no longer runs continuously.

The control panel cycles the fan off for some period of time each hour. For large motors, this cycling may increase the wear on belts and bearings to the point that the reduction in energy cost is negated. For this reason, in this scenario the chiller is not cycled. Also, interrupting the fan may disrupt air circulation in the room, causing hot and cold spots. The control panel shortens the time of the off cycle if the sensor for the room temperature reports that the desired setpoint is not being reached.

Demand Limit (Strategy K)

Since the air handling unit can be turned off for a short period of time without immediate detrimental effect on the occupants, it is possible to avoid using it at those times when other loads are causing the facility's demand (in kilowatts) to reach a peak. Lowering the peak in this way will reduce the substantial demand charge made by utility companies, or, in the case where the utility plant is part of the facility, reduce the cost of maintaining peaking capacity.

In this scenario, if the facility's demand goes above some desired level, the control panel will turn off the air handling unit for 15 minutes. At the end of that 15

minutes, the control panel will turn off some other piece of equipment and turn on the air handling unit. Two other pieces of equipment will, in turn, be turned off for 15 minutes and restarted. Just before the fourth piece of equipment is to be turned back on, the control panel will again turn off the air handling unit. By using four pieces of equipment of equal kilowatt consumption (four load shed groups), each turned off for 15 minutes and turned on 45 minutes, the peak demand is reduced by the kilowatts that would have been used by one of the pieces of equipment. Naturally, this strategy requires that all four load shed groups be connected to the same control panel so that they stay in sequence.

Other Strategies

Many other strategies have been defined in the literature, but the above are all that will be evaluated in this scenario.

Point List

For each air handling unit or other piece of equipment, a list is prepared summarizing the strategies evaluated and the sensors and controls required to implement each strategy. Since many strategies require the use of the same sensor or control, the list is usually prepared as a matrix. Each individual sensor or control is called a point, and the list will describe all the points that would

be installed if all the strategies are implemented. The point list for the air handling unit for this scenario is shown as figure 1. For convenience, figure 1 also shows the estimated reduction in energy consumption for each strategy and the cost to install each point.

POINT NAME AND FUNCTION	COST	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
27 Hot water supply temp	$649		*		*											
26 Chiller safety alarm	$70														*	
25 Condensor fan status	$70														*	
24 Chilled water pump status	$78												*		*	*
23 Water temp controller	$194									*						
22 Water temperature level	$162		*		*					*					*	
21 Water pump on/off	$73	*	*		*			*								
20 Pressure across filters	$300															*
19 Supply air temperature	$544								*						*	
18 Mixed air temperature	$544														*	
17 Return air humidity	$600						*								*	
16 Return air temperature	$544						*								*	
15 Cool coil valve status	$550									*					*	
14 Cool coil valve control	$775								*							
13 Reheat valve status	$550								*						*	
12 Outside air damper status	$550			*	*	*	*						*			
11 Outside air open/close	$459			*	*	*	*									
10 Outside air adjustment	$775															
9 Fan status	$300												*		*	*
8 Fan on/off control	$290	*	*		*			*			*	*				
7 Room humidity level	$600		*		*				*	*				*		
6 Room air temperature	$549		*		*				*	*	*			*		
5 Outside air humidity	$600		*				*							*		
4 Outside air temperature	$549		*	*		*	*	*						*		
3 Utility demand meter	$1,704											*				
2 Building fuel oil meter	$1,704													*		
1 electricity meter	$1,704													*		
— Networked System required												*				

ENERGY REDUCTION STRATEGY	$/YEAR
A. Scheduled start/stop	$1,561
B. Optimum start/stop	$23
C. Ventilation/recirculation	$63
D. Day/Night setback	[not
E. Economizer	[esti-
F. Enthalpy	[mated]
G. Outside air limit shutoff	$40
H. Reheat coil reset	$540
I. Chilled water reset	$8
J. Duty cycle	$26
K. Demand limit	$3
L. Feedback	[no
	[direct
M. Monitor	[energy
N. Troubleshoot	[reduc-
O. Preventative maintenance	[-tion]

ENERGY MONITORING
AND
CONTROL SYSTEM
POINT LIST
(PART 1)

figure 1

	POINT NAME AND FUNCTION	COST	SIGNAL TYPE		MEASURED/CONTROLLED
27	Hot water supply temp	$649	ANALOG	INPUT	Water temperature
26	Chiller safety alarm	$70	DIGITAL	INPUT	Auxiliary contact
25	Condensor fan status	$70	DIGITAL	INPUT	Auxiliary contact
24	Chilled water pump status	$78	DIGITAL	INPUT	Differential pressure
23	Water temp controller	$194	ANALOG	OUTPUT	Control point adjust
22	Water temperature level	$162	ANALOG	INPUT	Water temperature
21	Water pump on/off	$73	DIGITAL	OUTPUT	Motor controller
20	Pressure across filters	$300	DIGITAL	INPUT	Differential pressure
19	Supply air temperature	$544	ANALOG	INPUT	Air duct temperature
18	Mixed air temperature	$544	ANALOG	INPUT	Air duct temperature
17	Return air humidity	$600	ANALOG	INPUT	Percent humidity
16	Return air temperature	$544	ANALOG	INPUT	Air duct temperature
15	Cool coil valve status	$550	ANALOG	INPUT	Position indicator
14	Cool coil valve control	$775	ANALOG	OUTPUT	Control point adjust
13	Reheat valve status	$550	ANALOG	INPUT	Position indicator
12	Outside air damper status	$550	ANALOG	INPUT	Position indicator
11	Outside air open/close	$459	DIGITAL	OUTPUT	Open/close actuator
10	Outside air adjustment	$775	ANALOG	OUTPUT	Control point adjust
9	Fan status	$300	DIGITAL	INPUT	Differential pressure
8	Fan on/off control	$290	DIGITAL	OUTPUT	Motor controller
7	Room humidity level	$600	ANALOG	INPUT	Percent humidity
6	Room air temperature	$549	ANALOG	INPUT	Room air temperature
5	Outside air humidity	$600	ANALOG	INPUT	Percent humidity
4	Outside air temperature	$549	ANALOG	INPUT	Air temperature
3	Utility demand meter	$1,704	ANALOG	INPUT	Kilowatt pulse meter
2	Building fuel oil meter	$1,704	ANALOG	INPUT	Gallons (pulse meter)
1	electricity meter	$1,704	ANALOG	INPUT	Kilowatt-hour meter

ENERGY MONITORING
AND
CONTROL SYSTEM
POINT LIST
(PART 2)

figure 1 (continued)

NOTES

a. Cost for point and wire only.
b. Cost for points on chiller (21 to 26) prorated among three air handling units. 1/4 charged here.
c. INPUT = sensor sends a signal to the system (to building loop).
d. OUTPUT = control device receives a signal from the system.
e. Part 1 shows estimated reduction in energy per year for this air handling unit for each strategy.

Selecting Which Strategies to Implement

Since the purpose of the proposed Energy Monitoring and Control System is to reduce the consumption of energy, the strategies selected for implementation should be those that have the greatest reduction for the least cost. The criteria for selection will be the economic payback period.

The last four strategies in figure 1 (letters L, M, N, and O) do not reduce the consumption of energy and so will not be considered in this scenario until later. The reductions for these strategies are in labor or other operating costs. Some Energy Monitoring and Control Systems have been justified soley or largely on the reduction in operating costs, so an evaluator could look at these strategies at this stage. The criteria for this scenario is to first spend the least money possible to make a maximum reduction in energy consumption.

The point costs used will be only those directly connected to the air handling unit or chiller. This is the direct cost associated with each strategy. Other points, such as outside air temperature, can be shared by many air handling units if connected to a system. So rather than try to estimate this particular air handling unit's share of that point's cost, the point will be neglected for now.

Also, the cost of the control panel can be shared among many air handling units, and so will not be considered here.

In figure 1, the strategies that reduce energy consumption are lettered A, B, C, H, I, J, and K. The total annual reduction in energy for these is $2,269. To install all the points for these strategies is estimated to cost $5,945. The economic payback is 2.62 years. Even considering that none of the other costs have been included yet, this is a very good payback for an Energy Monitoring and Control System application.

While it would appear that all the strategies should be selected for use, not all of the money spent to install the points is well spent. If only one strategy was to be implemented, then the one with the lowest economic payback would be selected. Therefore the total cost for each strategy must be individually calculated. Figure 2 presents the results in a format similar to the point list. The paybacks range from 0.23 years to 256.88 years. Obviously, strategy A (scheduled start/stop) would be the first strategy to be selected.

figure 2

RANK STRATEGIES BY ENERGY PAYBACK ON COST OF ADDED POINTS

ITERATION # one   The cost of points "installed" during the last iteration are set to zero.

*	POINTS INSTALLED ON AIR HANDLING UNIT															ON CHILLER **							SAVING	COST	PAYBACK	*
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	$/YR	$	***	
A			290													73							$1,561	$363	0.23	A
B	549	600	290													73	162					649	$23	$2,323	101.00	B
C						459	550																$68	$1,009	14.84	C
D	549	600	290			459	550									73	162					649	same as (B) + (C)			D
E						459	550				544												[not]	$1,553		E
F						459	550				544	600											[estim.]	$2,153		F
G			290													73							$40	$363	9.08	G
H	549	600						550	775					544									$540	$3,018	5.59	H
I	549	600								550							162	194					$8	$2,055	256.88	I
J	549		290																				$26	$839	32.27	J
K			290																				$3	$290	96.67	K
L				300			550												78				[no]	$928		L
M	549	600																					[energy]	$1,149		M
N				300				550		550	544		544	544			162		78	70	70		[saved]	$3,412		N
O				300											300					70			[ ]	$670		O

NOTE * : Code letter for Energy Monitoring and Control strategy

NOTE ** : Costs and savings for chiller prorated among air handling units served by the chiller.

NOTE *** : Strategy selected by this iteration is that with the lowest incremental payback

$$\text{INCREMENTAL PAYBACK} = \frac{\text{(Cost of points that must be installed for strategy) - (Cost of those points already installed by previous iterations)}}{\text{Energy savings for strategy}}$$

	SAVING	COST	PAYBACK
CUMULATIVE	1561	363	0.23

(FOR ENERGY SAVING STRATEGIES ONLY!)

——>Strategies installed (including this iteration):   A

If the criteria was to select all strategies that had a payback of six years or less, from figure 2 only one other strategy would be chosen: strategy H (reheat coil reset). However, after implementing strategy A, two points have been installed. The cost of these points should not be included in the cost of other strategies that share these points. Figure 3 shows the resulting costs for each strategy. Instead of strategy H, strategies G (outside air limit shutoff) and K (demand limit) would be selected because they both have zero cost. The additional costs over the cost for just strategy A divided by the additional reduction in energy consumption is called the incremental payback.

figure 3

RANK STRATEGIES BY ENERGY PAYBACK ON COST OF ADDED POINTS

ITERATION # two   The cost of points "installed" during the last iteration are set to zero.

	POINTS INSTALLED ON AIR HANDLING UNIT															ON CHILLER **							SAVING	COST	PAYBACK	
*	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	$/YR	$	***	*
A			290													73							$1,561	$363	0.23	A
B	549	600	0													0	162					649	$23	$1,960	85.22	B
C						459	550																$68	$1,009	14.84	C
D	549	600	0			459	550									0	162					649	same as (B) + (C)			D
E						459	550				544												[not]	$1,553		E
F						459	550				544	600											[estim.]	$2,153		F
G			0													0							$40	$0	0.00	G
H	549	600						550	775					544									$540	$3,018	5.59	H
I	549	600								550							162	194					$8	$2,055	256.88	I
J	549		0																				$26	$549	21.12	J
K			0																				$3	$0	0.00	K
L				300			550												78				[no]	$928		L
M	549	600																					[energy]	$1,149		M
N				300				550		550	544		544	544			162		78	70	70		[saved]	$3,412		N
O				300											300					70			[ ]	$670		O

NOTE * : Code letter for Energy Monitoring and Control strategy

NOTE ** : Costs and savings for chiller prorated among air handling units served by the chiller.

NOTE *** : Strategy selected by this iteration is that with the lowest incremental payback

$$\text{INCREMENTAL PAYBACK} = \frac{\text{(Cost of points that must be installed for strategy)} - \text{(Cost of those points already installed by previous iterations)}}{\text{Energy savings for strategy}}$$

——>Strategies installed (including this iteration): A G K

	SAVING	COST	PAYBACK
CUMULATIVE	1604	363	0.23

(FOR ENERGY SAVING STRATEGIES ONLY!)

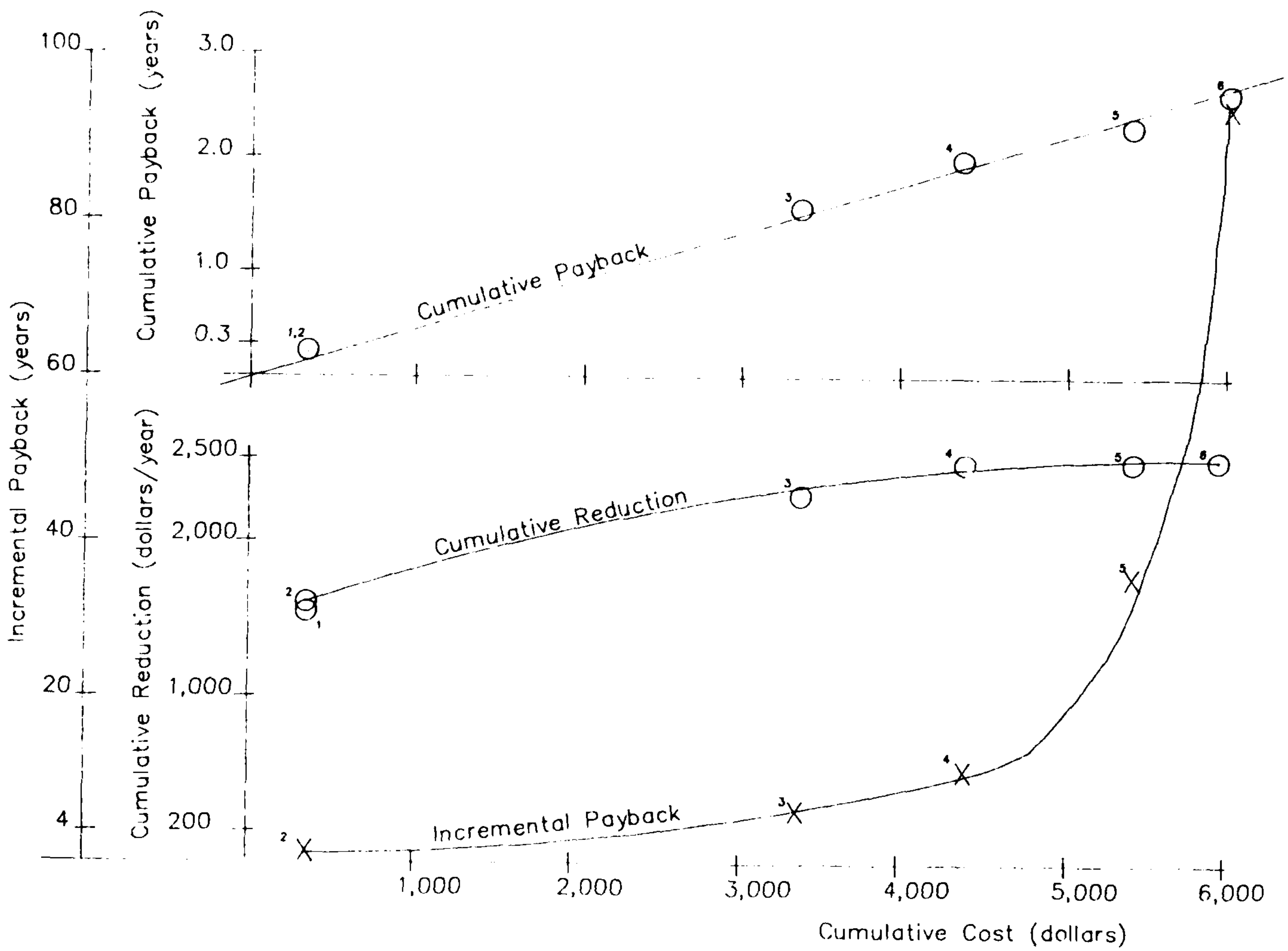
The incremental paybacks can then be calculated through several iterations, as seen in Appendix B for this scenario. The results are tabulated to show the effects of each iteration:

Iteration number:	start	1 & 2	3	4	5	6
Chosen strategy:	-	A,G,K	+H	+J,C	+B	+I
Cost of points						
Cumulative:	0	363	3,381	4,390	5,201	5,945
Incremental:		363	3,018	1,009	811	744
Energy reduction						
Cumulative:	0	1,604	2,144	2,238	2,261	2,269
Incremental:		1,604	540	94	23	8
Economic payback						
Cumulative:	-	0.23	1.58	1.96	2.30	2.62
Incremental:		0.23	5.59	10.7	35.3	93.0

The two paybacks and the cumulative savings are plotted against cumulative cost in figure 4. Just using cumulative payback as a measure for selecting strategies can be deceiving. For this scenario, the cumulative saving line flattens out as more money is spent to implement strategies. As a result, the incremental payback line climbs rapidly as the cost increases.

figure 4

RANK STRATEGIES BY ENERGY PAYBACK ON COST OF ADDED POINTS



For this scenario, strategies chosen during iterations 1, 2, and 3 will be selected for implementation. After iteration number 3 the incremental payback rapidly rises. Actually, the incremental payback from iteration 2 to 3, 5.59 years, is on the limit of the payback criteria typically used for Energy Monitoring and Control Systems. The strategies are:

A. Scheduled start/stop;

B. Outside air limit shutoff;

C. Demand limit; and

D. Reheat coil reset.

Note that to implement these strategies, only seven of the possible 22 points for the chiller and air handling unit will be installed (and five of these are for strategy D).

Network Add-On Strategies

These are the last four strategies listed in figure 1. These strategies reduce labor or other operating costs. Indirectly, they may also enable the facility operator to reduce the consumption of energy.

Feedback (Strategy L)

This strategy provides for some sort of notification (or alarm) to the facility operator if the device operated by the control panel fails. For example, a differential pressure sensor is installed across the inlet and outlet of the fan. If the control panel tells the fan to turn on

(say during the warm-up of the building), but the fan's differential pressure remains at zero, the control panel can issue an alarm that the fan did not start. This allows the facility operator to check on the fan right away, not after the occupants arrive and call to complain.

Since the Energy Monitoring and Control System attaches more gadgets to the air handling unit, there is a greater chance of failure. The occupants may feel that, even after a few failures, that the system is a failure and will not cooperate with the facility operator in implementing other energy reduction programs. It would be extremely difficult to put a dollar value on avoiding this situation, and one is not given in this scenario. The facility operator must evaluate the temperament of the building's occupants and the added cost of this strategy, then decide accordingly.

Feedback would be very desireable for an air handling unit whose failure would have a measureable detrimental effect on the occupants or the process equipment. Installation of this strategy would enhance the service provided to such critical rooms since the facility operator can now be quickly aware of problems.

Monitoring (Strategy M)

This strategy concurrently records the outside air parameters (temperature and humidity) and the building consumption of utilities (electricity and the heat source such as fuel oil). Traditional meters record the cumulative consumption for one month. But by recording the consumption over small increments of time, say 15 minutes, a demand curve can be plotted. The actual reduction in energy caused by implementing some strategy can be audited from a comparison of the demand curve to the times the strategy was in effect (such as when the air handling unit is duty cycled). Comparison of the the demand curve to occupancy patterns may highlight possible areas for reduction in consumption. For example, if the occupants go to lunch at the same time but the demand curve does not drop, then the supervisors could be made aware of the need and benefits of encouraging their subordinates to turn off lighting and process equipment.

This strategy can indirectly save energy in that the reports can be used to evaluate the existing energy program, help to identify sources of unexplained consumption peaks, and give the occupant a tool to measure the success of conservation actions. Many occupants will be more aware of the energy they consume if they receive a

periodic report. The reduction in consumption each year if such periodic reports are provided is estimated, for this scenario, as 1/2 of one percent of the total building consumption. If a demand plot can be made, then the reduction is doubled to one percent.

Using these guesses in the scenario, the net reduction in operating costs can be estimated:

(for entire building)	periodic report	Continuous demand plot
Reduction in energy consumed		
1/2% total consumption:	($40)	
1% total consumption:		($80)
Added labor for meter reading		
Assuming that reports must be retrieved at each building:	$56	
Assuming reports collected from a central location:		($56)
Prepare report for occupant and for the facility operator:	$84	$84
Net increase/(reduction) per year:	$100	($52)

Although there is a net cost shown, the facility operator may judge that the intrinsic value of the report to the occupant will justify the expense. Also, the estimate of the reduction in consumption used here is conservative.

Troubleshoot (Strategy N)

Most air handling units have various gauges and indicators mounted throughout the mechanical spaces to assist the tradesman in tuning and troubleshooting. For

example, a thermometer in the supply air duct can be used by a controls technician to calibrate the setting of the cooling coil valve. A thermometer on the refrigerant (the chilled water), though, may indicate that the chilled water is at an improper temperature. An air conditioning mechanic would check the operation of the chiller.

By remoting these sensors and presenting these in some organized fashion, the facility operator can observe potential troubles developing. In the case where an alarm has been received, such as the room air temperature is above the desired setpoint, the operator could determine where the problem may be and dispatch the proper tradesman. This strategy will allow the facility manager to better react to a developing problem rather than responding to a crisis when the system fails.

Preventative Maintenance (Strategy 0)

For an air handling unit, this strategy monitors the use of those elements of the system that require frequent maintenance. The most common is to record the total hours a motor has operated (the run-time). Lubrication is performed at the times the motor has actually operated a certain number of hours rather than at some guess of elapsed calendar time. The second is to record the

differential pressure across the filters. Filters are replaced when the pressure indicates that they are dirty, not on an estimated calendar schedule. Note that the differential pressure across the filters also gives to the operator an indication that the fan in or is not operating.

Since the major cost of maintenance is the labor used to visit the equipment, and since the calendar elapsed time estimates are usually conservative, the cost of maintaining the equipment is reduced if fewer trips are necessary. Conversely, poorly lubricated motors and dirty filters cause the air handling unit to consume more energy.

CHAPTER 5
SELECTING THE SYSTEM

Having selected the strategies to be implemented, the facility operator has a list of the number and types of points to be controlled and a description of the functions to be performed. The system selected must: (1) be of the size and have the capability to physically connect to the points; and (2) perform the control functions in a manner to suit the facility operator.

In this report, the Energy Monitoring and Control System is divided into four parts.

The first part consists of the existing controls on the equipment, sometimes called the local loop. For the air handling unit in the scenario, one of the the local loops is described by the opening and closing of the reheat coil valve by the room air thermostat. The local loops are not strictly part of the Energy Monitoring and Control System. However, most energy reduction strategies function by interrupting or overriding the adjustment of the local loop. For example, the reheat coil reset strategy (H) overrides the adjustment of the cooling coil valve to lower the supply air temperature. The cooling coil valve is

adjusted in a local loop by the supply air thermometer. This strategy would fail if the room air thermostat failed to note the increase in room temperature and close the reheat coil valve. The local loop must be completely understood so that the proper points can be specified to implement the strategy. Also, failure of the local loop could cause the strategy to fail or not reduce the consumption of energy by the amount predicted.

The second part consists of the various points (sensors and controls) connected to the building subsystem. This includes the wire or pneumatic pipe that connects the point to the rest of the Energy Monitoring and Control System. These points are inserted into the local loops or measure status (such as temperature or differential pressure). This part serves as the interface between the physical location, sometimes called the data environment (DE), and the rest of the system.

The third part, called the building loop in this report, consists of those components that are shared by all of the controlled equipment in one building.

The fourth part, called the system loop in this report, consists of those components shared by all the controlled buildings.

This geographical division of an Energy Monitoring and Control System was not common in current literature. However, there appears to be no one particular classification method that is generally accepted and well defined. Accepting the risk of creating yet another scheme, the four divisions and their subdivisions described herein will be used as building blocks from which the facility operator can choose to build the proposed system.

Building Loops

The building loop has undergone the most change in recent years as the result of the miniaturization of computor components using new solid state technology. More capability can be put in a smaller and less expensive box than in the past. A list of these boxes follows, each given a letter code. The costs given are estimates for the building loops only and do not include point costs. (36)

Timeclock (Loop A)

The mechanical timeclock is simple to understand. It is also simple to install. If more than just a few are installed, the facility operator usually specifies a seven

day clock with a spring-wound backup. The seven day feature allows a different on/off schedule for the weekends from weekdays. In case of a power outage, the spring winding will operate the clock for a few hours. The timeclock is usually restricted to only one "off" and one "on" per day. The timeclock has to be kept locked since it is very easy for the occupant to tamper with the settings. Unfortunately, the system then cannot be overridden without a key to the box. However, the price is low: cost installed (as of end of 1981) is $224.

Smart Thermostat (Loop B)

The mechanical clock of the timeclock is replaced by solid state circuits, and packaged with a thermostat. Since the thermostat is usually connected to the same points as needed for start/stop operation (in this scenario it is connected to the reheat coil), a smart thermostat eliminates the cost of the control points. The second advantage is that a schedule override can be made easily available. The setpoints are usually entered by a certain sequence of keystrokes, and the schedule is not easy to change. The smart thermostat is not truly a building loop since, with the thermostat, one unit must be used for each air handling unit. The cost installed is $200, attractive if installed as a replacement for a failed thermostat.

Building Controller (Loop C)

This device is the solid state equivalent of mounting several time clocks into one cabinet. Those with eight load capacity groups can provide start/stop control for all the major equipment of a small building. Most can schedule many on/off times, usually in five minute increments. Cost for a unit with this ability averages $1600.

Demand Limiter and Duty Cycling (Loop D)

This is a building controller with the added programming to support demand limiting. One with eight load groups can provide adequate control for a small building. Since each load group shares the same internal clock, the off schedules can be synchronized so that one of the groups is off at any one time, thereby implementing the demand limit strategy. The unit provides an input for a point to sense the kilowatt consumption of the building. The unit can be programmed to start the duty cycling schedule when the consumption reaches a certain trip point. Average installed cost for a unit of this capability is $3,300.

These units are sometimes seen in facilities with emergency generators. The programming allows the load groups to be arranged by priority, so that each load group in turn can be shut off completely if the consumption exceeds the capacity of the generator.

Multiplexer Panel (Loop E)

The multiplexer panel (MUX) mixes the individual signals from the points into one signal. Most of the signals from the points (and control signals to the points) have a short range because of electrical noise or line resistance. Also, installing many wires for long distances is expensive. This panel is then located convenient to the points. The output from the multiplexer (the mixed signal) is passed to the input of a modem (modulator-demodulator) or a line driver. The modem converts the signal into a format suitable for transmission over long distances, such as over telephone lines. The line driver amplifies the signal to the extent necessary to overcome line resistance.

Many times the wires from the points are connected to terminal strips located in a data terminal cabinet (DTC). The wires lead from another terminal strip in the data terminal cabinet to the input side of the multiplexer. This allows the points to be installed and checked out independent of the rest of the system, and allows the outputs from the multiplexer to be checked independent of the points. Jumpers are used inside the data terminal cabinet to connect the two. (24,pp.5-3 to 5-7)

The multiplexer simply passes on whatever is sent to

it, it is simply a convertor. Any control logic must therefore be found upstream (in the system part). The cost with modem and data terminal cabinet is $4,003.

Intelligent Multiplexer Panel (Loop F)

The intelligent multiplexer panel (IMUX) performs the identical function as the multiplexer panel (MUX) except that it only "reports by exception". The unit receives signals continuously, but only converts and passes on those signals that change. It scans the sensor inputs so many times per second. On each scan it compares the current signal to the signal from the last scan. If it is different, that new signal is passed to the modem. Similarly, the unit maintains the control signal to a control point until it receives a certain signal from the modem (which is from some system upstream). The advantage is that the communication between the building loop and system is kept to a minimum. The cost is the same as for the multiplexer panel: $4,003.

Field Interface Device (Loop G)

The field interface device (FID) is a microcomputor device that has some limited control over the points. Communication between the microprocessor and the points is through an internal multiplexer module. An internal modem permits communication between the microprocessor and the

upstream system. The field interface device can simply pass signals between the system and the points. It also has the ability to implement some of the control strategies. The setpoints and schedules for such strategies are loaded into the microprocessor from upstream (the system). The advantage is that the strategies would still be implemented during any times that the rest of the system is not functioning. The cost, including a data terminal cabinet, is $5,588.

Satellite Layout (Loop H)

The field interface device typically must be connected to a large number of points to justify its expense. It therefore is located where it can serve as the focus for the signals from several buildings. The field interface device is located in one building and connected to points there using the internal multiplexer module. The nearby building will have a multiplexer loop (MUX, loop E) or an intelligent multiplexer loop (IMUX, loop F) to which that building's points are connected. The mixed signal is passed through a modem or line driver to the field interface device. The field interface device communicates for all the points with the system upstream. This is an advantage if the system is far away or the cost for connection is high.

Stand-Alone Unit (Loop I)

Through application of computor technology, the old style field interface device has grown to have the capability of performing most of the strategies for a single building. The device communicates upstream to coordinate strategies such as demand limiting, to pass information as requested by the system, and to receive new setpoints or schedules. In some cases the system is not connected all the time: it will connect to the device using a telephone auto-dial/auto-answer modem whenever information or an alarm needs to be passed. The control logic largely resides in the stand-alone unit, not in the system as found in the multiplexer loop (E).

Single Building Controller (Loop J)

This is simply a stand-alone unit that is not connected at all to an upstream system. To enter setpoints and schedules, each unit will have its own keyboard or will have an outlet to plug a portable keyboard into. The unit will have a liquid crystal display (LCD) or printer, or an outlet to which a portable device can be connected. The programming language is more understandable than the smart thermostat (loop B) and schedules are easy to modify. Most single building controllers still have, or the option to have, the programming to allow communication with a system. The average cost is $8,800.

Fully Distributed Processing (Loop K)

Rather than the single building controller talking upstream to some central system, the internal programming allows it to talk to other single building controllers. Information can be shared and conceivably the internal clocks could be synchronized to implement demand limiting. Such units can be connected to the local area networks (LAN's) that are being installed in some buildings, avoiding the cost of installing a dedicated network. (37)

System Loops

The system loop provides the centrally located functions found in the Energy Monitoring and Control System. The system loop communicates to the building loop using: (1) twisted pairs of conductors; (2) coaxial cable; (3) dedicated telephone lines; (4) a radio frequency signal superimposed on the existing building electrical wiring (power line carrier (PLC)); (5) radio transmission; and (6) fiber optics. Collectively these are called the data transmission media (DTM). In this scenario, dedicated phone lines will be used. The assumption will be that a spare circuit is available for each of the buildings studied and that the phone lines are owned by the facility operator. Therefore no cost is included for installing circuits. (2; 24)

Master Control Room (System A)

All of the program logic and reporting functions are provided by equipment located in one place. This is typically used with the multiplexer building loop (E) or the intelligent multiplexer building loop (F). The signals from each of the many such loops are converted by a device (communications link termination (CLT)) consisting of modems and a signal concentrator. The signal is passed to the minicomputor, also called the central control unit (CCU). The minicomputor has the memory capability to remember and modify the control logic instructions. Using its central processing unit (CPU), the minicomputor follows these instructions to interprete the signal received, perform comparisons and calculations, and send out a signal to direct some action. Peripheral devices installed are: (1) real time clock (RTC) to sychronize all devices in the system; (2) bulk loader to transmit the program instructions directly to the computor's memory when the computor is turned back on after maintenance or a power failure; (3) memory protect power supply to provide battery power for a short period of time so that the computor can shut down during a power failure without losing the instructions in memory; (4) floppy or hard magnetic disk drives to permanently store the program instructions; (5) printer to provide printed reports; and

(6) a keyboard with a black and white cathode ray tube (CRT) screen to enter program instructions and to display text messages (called the system terminal). The cost for this equipment, not including the air conditioning nor construction of the room, averages $48,530. (13, pp.2-7 to 2-10)

Color Graphics (System B)

A capability to present reports on a cathode ray tube (CRT) screen using color graphics is frequently added to the master control room (system A). For example, the schematic of the air handling unit can be displayed along with the current values of the points. This display allows the facility operator to quickly understand the status of the equipment controlled. Another common use is to show locations for room air temperature sensors and their current value. This is better than the typical text output which simply labels values with a point name or number, which the operator compares to a drawing kept on file in the master control room. In installations that have a wide variety of types of air handling units or floor plans, the operator can quickly react to an alarm and move on to the next event. Also, the facility operator can easily experiment with setpoints: with the schematic displayed on the color screen, the operator can issue a command to change the setpoint or a command to turn on or off some

control device, then watch the results for the entire air handling unit in real time. However, the cost is high: adding the equipment to provide graphics will add $5,500 to the master control room cost. (32)

Facility Operator's Office (System C)

Some manufacturers are using microcomputors to provide central function control for building loops that have the capability for distributed processing (such as the stand-alone unit (I)). The central processing unit (CPU), memory, real time clock (RTC), floppy or hard disk drive, keyboard, and cathode ray tube screen is purchased off the shelf. A popular choice is the International Business Machine Corporation's Personal Computor (IBM PC). The functions of the communications link termination (CLT) as well as specialized electronics circuits are assembled into a coprocessor board. The coprocesser board and the program instructions are installed in microcomputor. The number of points controlled, the number of types of strategies that are available, and the ease of the programming language is currently less than the best minicomputor installations. Usually the most serious problem is the microcomputor, since it was not built especially for this function, is slower than the minicomputor. However, it is adequate for many installations, and the cost is much less: $6,500. (15; 17)

Dumb Terminal (System D)

By adding a small software program to an off-the-shelf microcomputor, and connecting it to the building loops with an auto-dial/auto-answer modem, the facility operator can communicate with the building loops only when needed. This frees the microcomputor for other tasks. The microcomputor does not provide any control functions, so the building loop must be able to stand alone. The software program allows the facility operator to retrieve and print reports from the building loops, and frequently also allows some changes to be made in the setpoints. The cost is about $3,000.

No Front End (System E)

If the Energy Monitoring and Control System does not have a central control location, such as one that consists entirely of single building controllers (loop I) or fully distributed processing units (loop J), it is said to have no front end. The facility operator must visit each building loop to individually change setpoints or to retrieve reports.

Initial Installation Costs

Fairly significant costs are incurred during the initial installation of any of these systems.

Software

There are three types of software that provide the program instructions for the central processing unit. The system software defines how memory is to be partitioned and manipulated, controls peripheral devices, and provides diagnostics, among other functions. The command software defines the keyboard keys or code sequences that enable the operator to operate the computor. Some specifications require the use of English language words. The application software reacts to data from the points and commands from the operator, performs comparisons and calculations, and directs output.

For the master control systems (A and B), the software cost is $33,000 for the size of the system in this scenario. For the microcomputor systems (C and D), the system software (commonly called the disk operating system (DOS)) is provided off the shelf. The command programs vary in capablility but appear to average $250. If control functions are at the microcomputor (system C), programs with different capabilities are available for prices up to $2,000. The software for the building loops are sometimes included with the price of the device.

Construction

Submittals of manufacturer's data, maintenance

information, shop drawings, and as-built drawings are usually required of the installer by the facility operator. For a master control room system (A or B), typically custom built from a number of components, the cost to prepare these submittals can be estimated as $5,000 plus $5 per point, and for their review by the owner as $4,350. For systems that are made up using stand-alone units or other such devices that are routinely packaged by the vendor with other devices to form a system, the submittal cost is naturally lower. Probably in the order of $1,000 plus $2 per point, and $500 for reviews.

The United States Navy requires that the master control equipment be assembled at the factory and tested using simulated points. The cost of this test is estimated at $5,300. The factory test will probably not be required for stand-alone units, or at most the manufacturer would have to submit a certificate that production samples were tested and met the specifications. (23; 25)

<u>Start-up</u>

Good practice indicates that the existing controls be checked to ensure proper operation and to confirm their as-built drawings. This is usually performed during the system design, however in practice it appears to be rarely

performed at all. This is expensive, a rule of thumb estimate of $36 per point installed. Once the point is installed, the information on that point and the control setpoints must be entered into the computor. This will cost $12 per point. The point has to be tested and calibrated individually and as part of the system, at $29 per point. Therefore, for any of the systems, $77 per point must be allowed for start-up costs.

If the system is capable of color graphics, the generation of each graphic display will cost at least $100.

The facility operator and console operators (if any) must be trained on the system. For master control room systems this could cost $6,500. For stand-alone units, due to their modular design and typically "cookbook" style instruction manuals, the training would be more on the order of $1,000.

The United States Navy requires that the contractor provide personnel to man the master control room for an initial thirty days, called the operational acceptance test. The cost is estimated to be $12,300. The stand-alone unit is generally left unattended, so it is unlikely that there will be a requirement for a manned

test. For this scenario, the cost will be estimated as zero.

Selecting the System from Total Installation Cost

The number of combinations of strategies, building loops, and system loops is staggering. Ideally, the facility operator would consider each combination. However the money spent for such a study would be better spent on actions that reduced the consumption of energy, even if the system selected is not the theoretical optimum.

For this scenario, only two building-system loop combinations will be compared. The first consists of the intelligent multiplexer building loop (F) and the master control room system (A). This is the classical network Energy Monitoring and Control System. The second combination consists of the single building controller building loop (J) with no front end (system E).

In chapter 4, the list of strategies was reduced to four based on economic payback. One of those, demand limiting (strategy K) cannot be implemented for an entire complex of buildings by the single building controller and so will not be considered. One of the add-on strategies will be considered, monitoring (strategy M), since it has

inherent advantages for which the facility operator cannot assess a dollar value.

The worksheet on which the costs and paybacks for the different combinations were calculated is provided by appendix C. The rest of this chapter picks numbers off of this worksheet in a search for trends.

Hold Size of System at 240 to 265 Points

Table 1 compares systems of the same size but different capabilities.

Table 1

STRATEGY	NUMBER OF POINTS	NUMBER OF BUILDINGS	INITIAL TOTAL COST	COST PER POINT	CUMULATIVE PAYBACK
for intelligent multiplexer (F) and master control room (A):					
A	240	60	$444,560	$1,852	1.19
A+M	242	40	$475,973	$1,967	1.89
A+G+H	248	13	$320,712	$1,293	2.88
A+G+H+M	254	12	$348,481	$1,372	3.37
for single building controller (J) and no front end (E):					
A	240	60	$619,180	$2,580	1.65
A+M	242	40	$554,647	$2,292	2.25
A+G+H	260	13	$277,385	$1,067	2.49
A+G+H+M	265	12	$299,711	$1,131	2.95

For systems of roughly the same number of points, the more strategies that are implemented the worse the payback gets. Another bad effect is that fewer buildings are then connected to the system. However, with fewer buildings there are fewer building loops to buy, and so the total cost per point drops. Apparently, the facility operator should be very selective in what strategies to implement to keep the total number of strategies small.

Hold the Number of Buildings controlled at 60

The facility operator for a large complex of buildings will be interested in connecting to many buildings so that a large percentage of the population can share in the benefits of the system. Also, the availability of uniform reports for a large number of buildings will enable the facility operator to compare consumption among different types of occupancies and types of buildings to target areas for further work. Table 2 compares alternatives.

Table 2

STRATEGY	NUMBER OF POINTS	NUMBER OF BUILDINGS	INITIAL TOTAL COST	COST PER POINT	CUMULATIVE PAYBACK
for intelligent multiplexer (F) and master control room (A):					
A	240	60	$444,560	$1,852	1.19
A+M	362	60	$665,813	$1,811	1.74
A+G+H	1,141	60	$1,062,231	$931	2.07
A+G+H+M	1,262	60	$1,277,233	$1,012	2.47
for single building controller (J) and no front end (E):					
A	240	60	$619,180	$2,580	1.65
A+M	362	60	$830,067	$2,293	2.25
A+G+H	1,200	60	$1,271,200	$1,059	2.47
A+G+H+M	1,321	60	$1,485,839	$1,125	2.93

By installing the system in the same number of buildings, as the number of strategies is increased, the number of points and therefore the total cost also increase. The cumulative payback still becomes worse as more strategies are implemented. For all four levels of strategies, the master control room system (F+A) has lower intial cost and quicker paybacks than the single building controller system (J+E). This is because points can be shared between building loops in the former.

Hold the Number of Buildings controlled at 13

The facility operator at a small complex will not have sixty buildings. The operator at a large complex may want to only connect a few buildings to keep the initial cost low. Table 3 compares alternatives.

Table 3

STRATEGY	NUMBER OF POINTS	NUMBER OF BUILDINGS	INITIAL TOTAL COST	COST PER POINT	CUMULATIVE PAYBACK
for intelligent multiplexer (F) and master control room (A):					
A	52	13	$186,389	$3,584	2.30
A+M	80	13	$233,189	$2,915	2.85
A+G+H	248	13	$320,712	$1,293	2.88
A+G+H+M	275	13	$367,830	$1,338	3.28
for single building control (J) and no front end (E):					
A	52	13	$135,214	$2,600	1.67
A+M	80	13	$182,830	$2,285	2.29
A+G+H	260	13	$277,385	$1,067	2.49
A+G+H+M	287	13	$324,422	$1,130	2.95

As expected, the initial cost of connecting to a few buildings is less than to a large number. However, the reduction in total cost for the single building control system (J+E) was so much greater than the reduction for the master control room system (F+A) that the former is now the lower in total cost and has the quickest payback. The payback still gets worse as more strategies are implemented even though the cost per point decreases. For both the case of sixty buildings as well as here for thirteen buildings, the trend in the cost per point is not much of a guide to the facility operator.

Hold to One Strategy But Vary the Number of Buildings

Since the number of buildings connected appears to have a large influence on the comparison between the two systems, a comparison will be made on the number of buildings in Table 4.

Table 4

STRATEGY	NUMBER OF POINTS	NUMBER OF BUILDINGS	INITIAL TOTAL COST	COST PER POINT	CUMULATIVE PAYBACK
for intelligent multiplexer (F) and master control room (A):					
A+M	80	13	$233,189	$2,915	2.85
A+M	242	40	$475,973	$1,967	1.89
A+M	362	60	$655,813	$1,811	1.74
for single building control (J) and no front end (E):					
A+M	80	13	$182,830	$2,285	2.29
A+M	242	40	$554,647	$2,292	2.25
A+M	362	60	$830,067	$2,293	2.25

For the same combination of strategies, as the number of connected buildings increases, the cost increases. However, here the cost per point and the payback decrease. Also the total cost, cost per point, and the payback for the two systems are equal at some number of buildings between 13 and 40. These are plotted on figure 5.

The relationship between the total inital cost and the number of buildings is linear for both systems. The slope for the single building control (increase in total cost per additional building) is steeper than for the master control room system.

The relation between cumulative payback and number of

buildings is curved. For the master control room system the payback is long for few buildings but drops rapidly as the number of buildings is increased. The single building system starts with a long payback and drops slightly as the number of buildings is increased, but after 35 buildings the slope of the curve (change in cumulative payback per increase in number of buildings) is zero.

The initial cost and the cumulative payback for the two systems cross in the range from 25 to 30 buildings. Based on initial cost, the master control room system (F+A) uses the money invested more efficiently if the installation involves more than 30 buildings. The single building system (J+E) is better for an installation of less than 25 buildings.

The incremental payback is also plotted on figure 5 using these figures from Table 5.

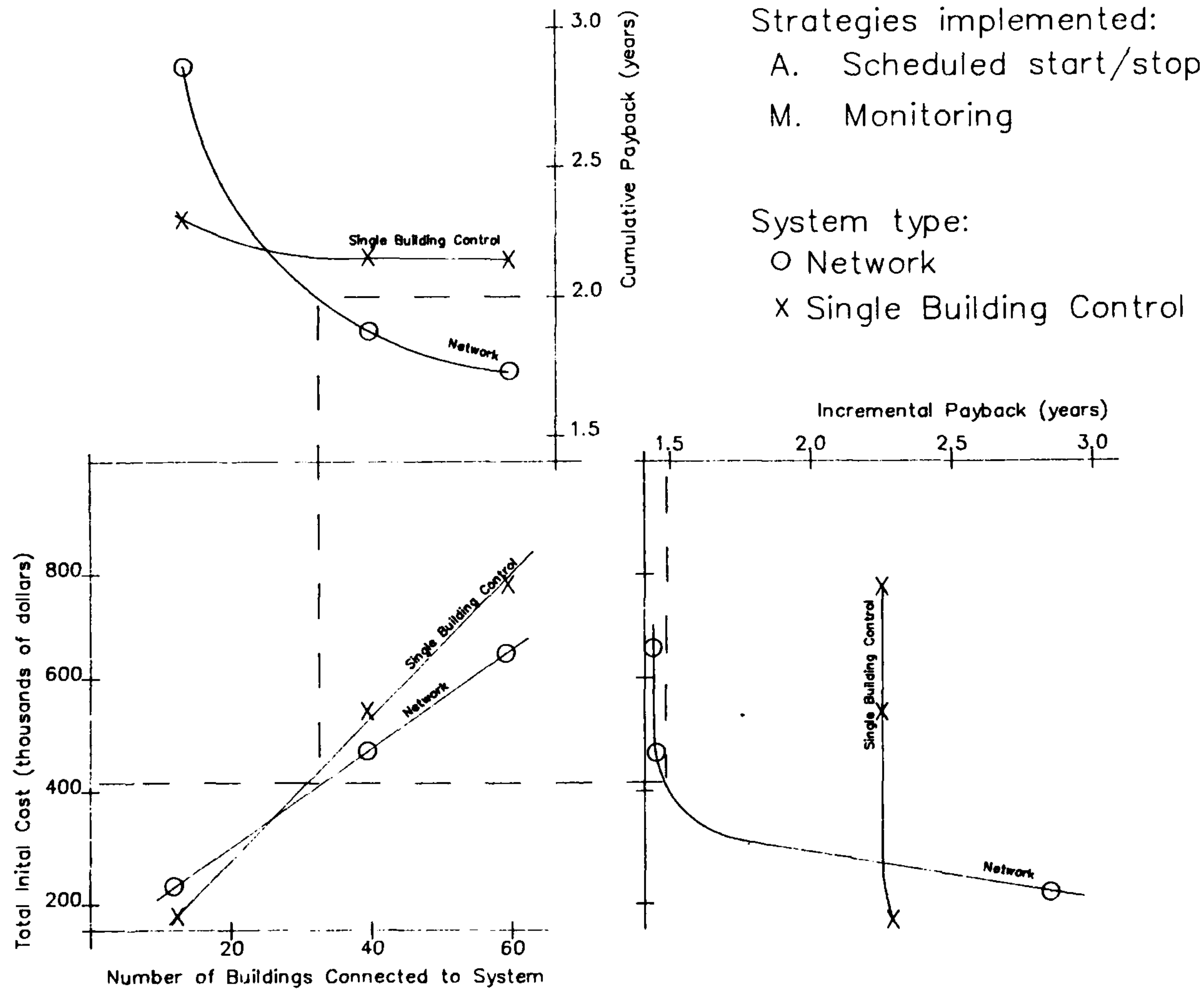
Table 5

INITIAL TOTAL COST		REDUCTION IN ENERGY		INCREMENTAL
CUMULATIVE	CHANGE IN	CUMULATIVE	CHANGE IN	PAYBACK
for itelligent multiplexer (F) and master control room (A):				
$233,189	$233,189	$81,848	$81,848	2.85
$475,973	$242,784	$251,840	$169,992	1.43
$655,813	$179,840	$377,760	$125,920	1.43
for single building control (J) and no front end (E):				
$182,830	$182,830	$79,872	$79,872	2.29
$554,647	$371,817	$245,760	$165,888	2.24
$830,067	$275,420	$368,640	$122,880	2.24

The incremental payback for the master control room system

figure 5

COMPARING PAYBACKS TO NUMBER OF BUILDINGS



improves quickly as more money is invested into it. Once the equipment in the master control room is paid for, expansion of the system by adding buildings has a very short payback. The single building control system does not require this initial investment, other than for some training and such construction costs as submittals. The payback on the investment of money to add a building is essentially the same as the payback for the initial system.

The two curves appear to intersect at an initial cost of $275,000. This will connect 16 buildings to the master control room system (F+A) or will connect 20 buildings to a single building control system (J+E). This compares to the range of 25 to 30 buildings where the cumumlative payback curves cross. Essentially, the master control system (F+A) uses the invested money much more efficiently than the single building control system (J+E) after the first sixteen buildings are connected, but not until 30 buildings are connected does this efficiency overcome the effect of the heavy front end cost.

If the facility operator only has a small lump sum amount that can be invested in the first year, but is committed to expanding that starter system a small amount each year, then the installation of a master control system

with only 16 buildings might be justified since the money invested in the system in the following years will return a higher payback than the single building control system. But the system has to be ultimately expanded past the number of buildings at the breakeven cumulative payback. The single building control system would be the most efficient use of money if the system will not grow past a small number of buildings.

Figure 5 makes an interesting nomograph for discovering the effects of the economic constraints of (1) available money to invest and (2) acceptable payback period. In practice a curve such as this would not be as easy to generate since every building has different equipment to be controlled, different reductions in energy consumption, and different mix and number of points. Each buiding could be listed by increasing length of payback. The cumulative reduction in energy and the cumulative cost for just the first building would be calculated, then calculated for the first and the second building, then again for the third building, and so on. Such an effort is best left to a computor.

Effect of Increase in Number of Strategies on Nomograph

Since the number of strategies implemented had such a detrimental effect on the payback when the system was held to a certain number of points or a certain number of buildings, the nomograph of figure 5 was replotted for the costs for a system that implemented a larger number of strategies using the information from Table 6.

Table 6

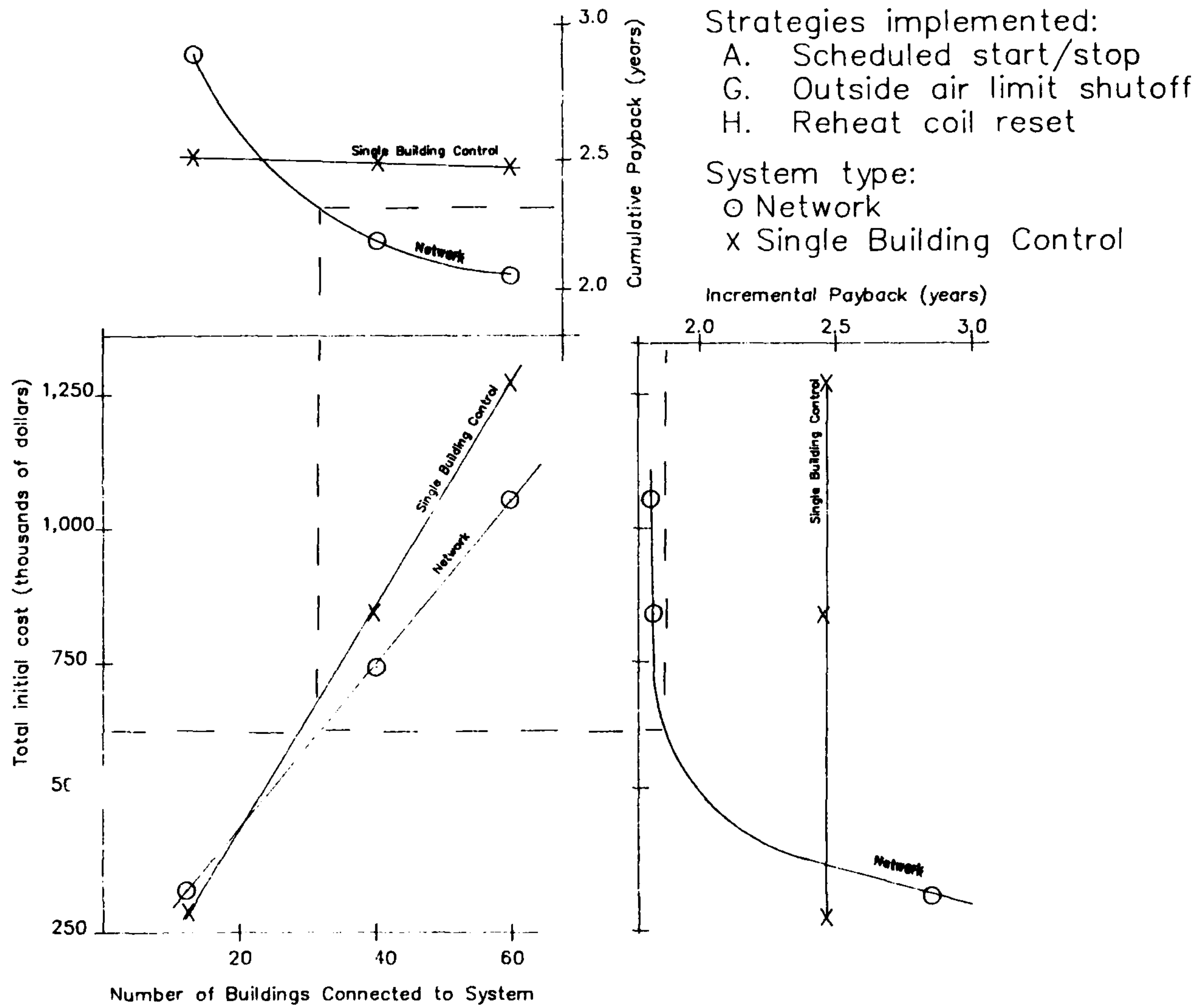
STRATEGY	NUMBER OF POINTS	NUMBER OF BUILDINGS	INITIAL TOTAL COST	COST PER POINT	CUMULATIVE PAYBACK
for intelligent multiplexer (F) and master control room (A):					
A+G+H	248	13	$320,712	$1,293	2.88
A+G+H	761	40	$746,691	$981	2.18
A+G+H	1,141	60	$1,062,231	$931	2.07
for single building control (J) and no front end (E):					
A+G+H	260	13	$277,385	$1,067	2.49
A+G+H	800	40	$848,300	$1,060	2.48
A+G+H	1,200	60	$1,271,200	$1,059	2.47

INITIAL TOTAL COST CUMULATIVE	INITIAL TOTAL COST CHANGE IN	REDUCTION IN ENERGY CUMULATIVE	REDUCTION IN ENERGY CHANGE IN	INCREMENTAL PAYBACK
for itelligent multiplexer (F) and master control room (A):				
$320,712	$320,712	$111,332	$111,332	2.88
$746,691	$425,979	$342,560	$231,228	1.84
$1,062,231	$315,540	$513,840	$171,280	1.84
for single building control (J) and not front end (E):				
$277,385	$277,385	$111,332	$111,332	2.49
$848,300	$570,915	$342,560	$231,228	2.47
$1,271,200	$422,900	$513,840	$171,280	2.47

These numbers are plotted in figure 6. The sh pe of the curves are similar to those of figure 5. The initial cost curves are shifted upward (higher initial cost for each building) which is reasonable given that there are more points installed per building. The two payback curves are shifted toward longer paybacks for the money invested. Otherwise, the nomograph is still a useful tool.

figure 6

COMPARING PAYBACKS AFTER INCREASING NUMBER OF BUILDINGS



CHAPTER 6
OPERATION AND MAINTENANCE

The facility operator, in selecting an Energy Monitoring and Control System, must evaluate not only the expected energy savings and initial cost, but must include the annual cost of operating and maintaining the system. Since paybacks are measured in years, steps must be taken to ensure the system will be performing like new in the outyears of its life. The full potential of the strategies to reduce energy consumption cannot be realized unless manhours are spent fine-tuning the setpoints and adjusting schedules to meet the occupant's needs. (17)

Unfortunately, very little is written on what type of maintenance is needed. Almost nothing is written on how much is enough. Some of the problem is that control equipment is advancing faster than the training provided to the tradesmen who must maintain it. As a result, little maintenance is performed other than "replace when breaks". More often, the controls are bypassed and no longer need maintenance. When maintenance is performed, records are not kept for individual devices. From such records could be determined the failure rate as well as the actual time spent on repair of each type of device. Keeping detailed

records use manhours and money, both of which the facility operator typically lacks. The following are some thoughts and guidelines found on this matter. (26; 27; 28; 29; 39)

Local Loop Maintenance

The existing, typically pnuematic, devices of the local loops must operate properly or additional energy will be consumed by the equipment. Pnuematic controls in particular are mechanical devices: controlling and being controlled by air pressure acting against diaphragms, springs, pistons, and levers. Each requires the setpoints to be adjusted to compensate for wear and must be checked for leaks. This requires a tradesman trained to use the tools and techniques for each device. In addition, the local loops must be exercised to ensure the devices are working together. This requires a tradesman that can read and understand control diagrams. At the minimum this should be performed once a year. (16; 35)

Dirt and Dust Removal

Dirt and dust are probably the worst enemies of the devices that make up the Energy Monitoring and Control System. Yet they must be installed in the dirtiest of environments: the mechanical room. Even the dust found in a typical office setting can cause troubles if not controlled.

The dirt can work into the contact surfaces between moving parts, causing excess wear. This leads to a shorter service life, leaks or greater play in the mechanism, or failure by jamming. The best solution is to prevent the entrance of dirt by ensuring gaskets and sheilds are tight and are being used.

Dust can cause damaging stray currents if a layer is allowed to built up on the surfaces of electronic equipment or on the electronic boards proper. Surfaces can be wiped clean, and dust removed from boards by blowing or vacuuming. Filters on cooling vents should be used and kept clean.

Dust and dirt reduces the ability of equipment to dissipate heat, very important for solid state equipment. Cooling fans should be checked to ensure proper air flow not only for heat removal but to keep dust from accummulating. Filters reduce the entry of dust but they must be regularly cleaned.

All components should be cleaned inside and out four times per year. (10)

Physical Condition

Twice a year the physical condition of all components should be checked.

Corrosion, especially at electrical contacts, should be cleaned and steps taken to prevent reoccurance.

Electrical checks that are typically performed are: comfirming system isolation (signal ground); checking earth ground and that cabinets are grounded; adjusting power supplies for proper voltage; and checking the condition of backup batteries.

Mechanical checks include: check that wiring connections are tight and components are firm in their sockets; check operation of switches; exercise relays and adjust gaps; ensure indicator lamps illuminate; and lubricate bearing surfaces.

Electronics maintenance

Electronic solid state devices can fail and their calibration can drift. Heat and static electricity can especially damage these components. To maintain accuracy, all solid state devices should be calibrated once a year.

For input points, as a minimum the computor reading given by the input point is compared to the actual reading. The actual reading is found by a portable device measuring at the same location as the input point. This protable device, called the standard, is itself laboratory calibrated routinely. If the two readings do not agree, the signal output from the sensor is checked. If this is within tolerance, a simulation device is connected to the computor and is compared to the readings given by the computor. The zero and span settings are adjusted or the circuit card replaced.

Output devices are exercised by the computor to ensure they operate. Reaction times from computor command to control operation can be checked. The failure modes of the controls should be exercised. (3; 18; 20)

Trouble Calls and Emergency Service

Trained technicians must be available to troubleshoot problems with the electronic components. This can be provided by force account or by service contract. Most of the computor equipment used have self-diagnostic programs to assist the operator. The typical repair is to replace the faulty circuit card or other modular component, so a

stock of spare cards or components is all that must be maintained. Very infrequently are repairs made on the circuit board.

Operation

The facility operator will usually designate someone to operate the computer. The operator will pull and prepare reports, dispatch tradesmen in response to alarms, and adjust program setpoints and schedules. If the system is large and the occupancy schedules change often, a full time operator is usually needed.

For a master control room system, the operator can quickly change many schedules, and the occupant can easily contact the operator by telephone. A twenty-four hour watch may have to be provided to support occupancy schedules that go into the night. The operator can quickly respond to alarms. The operator can also be tasked to review setpoints and experiment with modifications.

For a single building control system, the operator must visit each building to pull reports and make changes. A considerable part of the operator's time is therefore spent in travel. Schedule changes have to be arranged by the occupant in advance to prevent the cost of sending the

operator on a special trip to the building. If the schedule changes are few in number and reports are needed only on a monthly basis, a full time operator may not be needed. (8)

Training

New operators, tradesmen, and maintenance technicians must be familiarized with and trained on the equipment. (9)

CHAPTER 7
PROJECT RATIOS

Since the initial cost of the equipment is justified by the prospect of future reductions in utility purchases, any evaluation should consider the affects of inflation. In previous chapters, the analysis assummed that inflation would be zero.

The United States Navy dictates that an analysis for an Energy Monitoring and Control System assume a service life of 15 years. To compare alternatives, the costs over the entire service life must be reduce to common terms. One common way is to express the costs in terms of equivalent present costs. For example, if the estimated cost of the electricity that will not be purchased in the first year of operation is $1.00, and if the cost of electricity is projected to increase by 7% the following year, then the cost of electricity for the second year of operation will be $1.07. Assuming the cost of electricity will rise (escalate) by 7% each year for 15 years, the cost in year 15 (the future value) will be $2.58. The equivalent present cost in the first year (the present worth) can be visualized as the number of dollars that must be invested in a savings account that, after earning interest for 15 years, will have a balance of $2.58. If the interest rate

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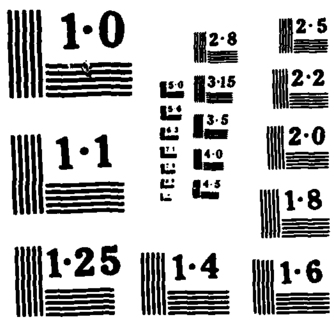

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

is 10% per year, the present worth is $0.62. The cost avoided in the present year is worth more to the facility operator than costs avoided in year 15, therefore the cost from year 15 are said to be discounted to $0.62.

In 1981, the Navy dictated that the facility operator use in the evaluation the assumption that electricity will rise by 7% per year, fuel oil by 8% per year, and operation and maintenance costs will rise by 5% per year. Any projections are sometimes as good as guesses. From 1981 to 1985, electricity did rise but at an average of 5% per year and fuel oil dropped by 8% per year. The discount rate to be used was 10%.

The simple payback used in previous chapters assumed the cost of energy each year will be the same as the first. If the present worth of the escalated costs for the 15 years was available in cash from a lender based on a promissary note earning 10%, the payments made each year would be the same. The payment amount represents the equivalent annual worth of the energy saved. The discounted payback is calculated by dividing the initial cost by the equivalent annual worth.

Another ratio commonly seen is called the savings to investment ratio (SIR). The present worth of the energy reductions is divided by the initial cost. A value of one means that the project returns over 15 years the same worth of money as was invested in the first year.

A commonly used measure of comparing investment alternatives is the rate of return. Instead of installing an Energy Monitoring and Control System, the money could be put in a savings account. The rate of return is the interest rate that the savings account must earn to generate the same worth of benefits as will be realized from the Energy Monitoring and Control System. This ratio is not used by the Navy, but would probably be used by a commercial enterprise since it must invest its money to earn the highest return to remain competetive.

The installation costs used in the previous chapter also did not include overhead, taxes, profit, and construction supervision. A conservative estimate is that this will add 35% to the project cost.

The various ratios are calculated in figure 7 for one of the alternatives evaluated earlier. Estimates for operation and maintenance are also included.

figure 7

PROJECT RATIO WORKSHEET

40 buildings Scheduled start/stop (A) Outside air limit shutoff (G) Reheat coil reset (H)		MASTER CONTROL ROOM (F+A)	SINGLE BUILDING CONTROL (J+E)
1. Project cost			
a. direct cost		$746,691	$848,300
b. overhead and profit (35%)		261,342	296,905
c. total present worth		$1,008,033	$1,145,205
2. Electricity reduction			
a. kilowatt hours (KWH):	3,027,150		
b. millions of British	X 0.116		
Thermal Units (MBTU):	35,115		
c. first year dollar reduction		$133,800	$133,800
d. total present worth* of reductions over project life (7% escalation)		$1,642,796	$1,642,796
3. Fuel oil reduction			
a. gallons #2 fuel oil:	193,300		
b. millions of British	X 0.1388		
Thermal Units (MBTU):	26,830		
c. first year dollar reduction		$208,760	$208,760
d. total present worth* of reductions year project life (8% escalation)		$2,737,261	$2,737,261
4. Non-energy reduction(increase)			
a. maintenance and service		($75,000)	($85,000)
b. operator		(40,000)	(10,000)
c. total in first year dollars		($115,000)	($95,000)
d. total present worth* of reductions over project life (5% escalation)		($1,241,770)	($1,025,810)
5. Total reductions			
a. MBTU per year (2b+3b): 61,945			
b. first year dollar (2c+3c+4c)		$227,560	$247,560
c. total present worth of reductions over project life (2d+3d+4d)		$3,138,287	$3,354,247
d. equivalent annual worth of total reductions (10% discount)		$412,591	$440,983
6. Ratios			
a. energy to cost ratio (E/C) [5a/(1c/1000)] MBTU per $1,000		61.5	54.1
b. simple payback [1c/5b] years		4.4	4.6
c. savings to investment ratio (SIR) [5c/1c] non-dimensional		3.11	3.82
d. discounted payback (using 10% discount) [1c/5d] years		2.4	2.6
e. rate of return (for 15 years) [calculated by iteration]		42%	41%

* Project life: 15 years. Discount: 10%.

The relative standing between the two systems remain unchanged even after performing these laborious calculations. It appears that the facility operator can carry out the bulk of the analysis using simple payback, and then calculate the effect of inflation for just a few alternatives.

CHAPTER 8
DIRECT DIGITAL CONTROL

Many stand-alone control units and single building controllers are advertised as having the capability to *perform direct digital control* (DDC). This relatively new development in the control of building systems is often confused with the concept behind an Energy Monitoring and Control System.

Direct digital control components are an alternative to the use of the traditional pnuematic components in the local loop. In the scenario, the cooling coil valve is controlled by the thermometor in the supply air duct. As the supply air temperature rises, the valve opens to lower the temperature of the cooling coil.

Using pnuematic components, the valve is operated by a lever connected to a piston. The valve is completely open when air at a pressure of 13 pounds per square inch guage (psig) is applied to the piston, and will be completely closed at a pressure of 3 psig. The temperature sensor operates a throttling valve on the main air supply such that the output pressure is 3 psig at 0 degrees Fahrenheit, and 15 psig at 100 degrees Fahrenheit. The designer of the system specified that the valve should be wide open at any

temperature above 60 degrees Fahrenheit and completely closed at any temperature below 40 degrees. At 40 degrees the thermometer will output 7.8 psig but the valve input has to be 3 psig. At 60 degrees, the thermometer will output 10.2 psig but the valve input has to be 13 psig. A device called a proportional pnuematic controller performs the conversion by applying the input pressure through a piston to a lever arm that controls a throttling valve on the main supply air. So in this relatively simple local loop, there are three pnuematic devices with a total of two throttling valves and two pistons. With time, the contact surfaces wear and the piston springs weaken, introducing small leaks and introducing inaccuaracies.

Using digital control components, the cooling coil valve is still operated by a piston and lever mechanism. The pressure to the piston is also still controlled by a throttling valve on the main air supply. However the throttling valve is operated by an electrical analog signal. The device, called a voltage-to-pressure transducer (E/P), can, in this instance, provide 3 psig output for a 0 volt input and 13 psig output for a 5 volt input. The thermometer can be one that provides an electrical output such that at 0 degrees Fahrenheit there will be an output of 0 volts, and at 100 degrees Fahrenheit

there will be a 5 volt output. Therefore at 40 degrees, the thermometer will output 2 volts and the valve will need to be 0 volts, and at 60 degrees the the thermometer will output 3 volts and the valve will need 5 volts. By connecting the valve and the thermometer to the microcomputor found in the stand-alone controller, a program can be written to instruct the computor to read the thermometer value, calculate the conversion, and output the proper voltage to the valve. In this local loop there is one throttling valve and one piston. The rest of the components are solid state.

The difference between the pnuematic loop and the direct digital loop is in how the control logic is defined. In the former, the logic is built up using components that act on another component. In the latter, the logic is given as a series of written instructions in a program. The program can be simple or it can be complicated and it can be modified during its life without changing any of the physical components. It is this flexibility that makes direct digital control so attractive.

Relationship to Energy Monitoring and Control Systems

The Energy Monitoring and Control System overrides the local loop in order to implement some control strategy. To implement the reheat coil reset strategy (H), the cooling coil valve setting is changed by the building loop controller until the reheat coil valve is completely closed. If for humdity control or other reason the cooling valve cannot be changed, the controller does not interfere with the setting dictated by the supply air thermometer.

In the pnuematic local loop, a second proportional controller is inserted into the air line to the cooling coil valve (in practice a two input proportional controller replaces the existing controller). The two controllers must be properly adjusted so that the proper level of control is given to the thermometer and to the building loop. However, there is another component to be maintained and another place for the local loop to fail.

In the direct digital local loop, the cooling valve is already controlled by the microcomputor. After connecting the heating coil valve and other sensors to the computor, the strategy is implemented simply by changing the program.

Fewer parts

One advantage is that there are fewer parts to maintain. Troubleshooting is easier due to the modular nature of the components. The sensors are connected independently of the others and so are easy to calibrate. The solid state components usually have some diagnostic techniques, and are repaired by plugging in a replacement. The disadvantage is that the solid state components are more expensive. Since they are not standardized, replacements are not as easy to obtain on short notice, so an expensive inventory may have to be maintained.

Reliability

Solid state components have theoretically an infinite life, but probably not quite so long a life in the hot, dirty, vibration-prone environment where they have to work. A solid state device usually fails completely and suddenly, requiring immediate repair. Pnuematic devices are mechanical and wear out, but the failure is gradual. Unfortunatly, as the pnuematic device wears out, it begins to waste more and more energy.

Interlock controls independent of the primary control are still needed, whether solid state or pnuematic. The interlocks should be able to override any other control and shut down the building service to prevent damage.

Control Algorithms

Several control strategies can be implemented easily by the direct digital loop, while the pnuematic loop is restricted to one or a few. Since the pnuematic components are mechanical, there is typically a time lag in the reaction of the control loop to a change. The digital loop can react faster to bring the system to equilibrium quickly. However, the facility operator may not be able to interpret the program, and thereby discover whether the algorithm used is proper for the application.

Changing Setpoints

Changing a setpoint in the direct digital loop is usually easier than in the pnuematic. The actual values desired must be converted to pressure values, and the loop must be checked for the effect of this new value on the other pnuematic components. The value of temperature, time, or other setpoint can usually be entered directly into the microcomputer. The entry procedure is a series of keystrokes or, in more elaborate programs, could be in reponse to prompts. The disadvantage is that if a wide variety of different control units are installed, the system operator may not be able to become proficient in using the equipment, and more time will be needed each year to train new operators.

Choosing to Implement Direct Digital Control

Very little has been written about actual experience with the operation of direct digital local loops. The ease of calibration and troubleshooting may offset the increased cost of the components and the alternative cost of maintaining pnuematic loops. The ease of changing setpoints may offset the chance that an algorithm is misapplied. The problem of having a wide variety of different makes of digital control units may be found to be less of a problem than the manhours now spent tracing a unique pnuematic control schematic for each piece of equipment.

There are apparently no standards for the interface between direct digital loops and Energy Monitoring and Control Systems. Some direct digital control units can provide the interface, but only to certain brands or types of systems. If the facility operator is contemplating the installation in the future of an Energy Monitoring and Control System, the digital control units installed now may have to be replaced or the equipment not connected. The facility operator wanting to install direct digital loops as part of the proposed Energy Monitoring and Control System will be constrained in the choice of equipment. (22)

CHAPTER 9
OPERATOR SURVEY

The operators of Energy Monitoring and Control Systems in the United States Navy were informally contacted to gain a feel for how the systems are actually being used. The data collected is not complete, but is enough to picture some trends.

Statistics

The operators of 39 operating, non-operating, and prospective systems were contacted. Eighteen systems were operating, eight were down, and thirteen were under construction, in design, or under study. The size of the systems that were operating ranged from 200 points to 6,000 points, the sizes pretty evenly distributed between 200 and 2400 points, with an average 1,350 points per system.

A large proportion of the systems monitor room temperature, but only a few directly control it. The most popular strategy is scheduled start/stop. Building steam valves were controlled by many of the systems. Only one reported performing demand limiting. Three of the systems were capable of only monitoring, no control. Six of the operators routinely used the system to troubleshoot and dispatch tradesmen. As a general observation, it appears

that only half of the operating systems report using strategies that require the use of a networked system.

For the majority of the systems for which someone was in charge, a full time energy manager was operating the system. Second choice seems to be the utility director. Nine of the systems have a full time operator during the day shift, but only three report a twenty-four hour watch. The operators were usually found in those systems with an energy manager. Power plant operators were the choice for part time operators.

More of the operators and maintenance technicians were journeyman electricians than any other trade. Personnel from the refrigeration or air conditioning shops were next.

Maintenance information that was fairly complete was gathered for only eight of the systems. Four of these have a maintenance service contract for the equipment in the master control room. In most cases, personnel in the energy groups are performing preventative maintenance on the building loops. Only three operators can afford to perform preventative maintenance on the sensors and relays. The rest of the operators report not having enough personnel to repair breakdowns, much less preventative

maintenance. Most sensors are not calibrated routinely. No operator reported that the local loops were being maintained other than when they failed to function.

Many of the operators commented that they had a free hand in implementing strategies as long as they kept the occupant happy. As a result, temperatures were not always kept at the standards. The first rule in this area is not to turn off the supply air fan during working hours: the occupant will complain even if the room air temperature is at the desired setpoint.

Six of the operators liked the network because it allowed available operators to control a large area.

Planning and Construction

The management of the planning for and construction of an Energy Monitoring and Control System is not the subject of this report, but it directly influences how the system will be operated.

The happiest operators seem to always be able to credit the personal interest taken by one person who worked through the construction and start-up. The facility operator in this way learns the system almost as well as

the contractor, and so there are usually no surprises nor misconceptions. Another advantage is that there is one liaison point for coordinating the work on the local loops.

Other operators commented that more thought needed to be applied in the selection of points. Some points selected were not useful to the operator. It appears that the facility operator was unable to express those thoughts during the planning process, or, due to new personnel, the goals changed.

Summary

The United States Navy has systems of a wide range of sizes, of strategies implemented, and of maintenance strategies used. Systems are working that demonstrate that the concept of an Energy Monitoring and Control System is useful to the facility operator.

CHAPTER 10
CONCLUSIONS

Developing an Energy Monitoring and Control System is a lot of work. The field investigation and preliminary analysis approaches that performed during design. Since the system design is based on economic paybacks, convenient planning factors are not available.

The facility operator must understand the constraints imposed by the nature of the occupancy and process equipment. The minimum service that is expected must be defined. This is not the same as the minimum service required, nor the same as minimum acceptable.

The purpose for which the money is invested should be clear. This can be defined in terms such as minimum payback or minimum energy reduction to cost ratios. Such criteria is needed throughout the analysis to keep it to a manageable size.

The intangibles must be identified and weighed for each strategy. Turning off the supply fan during working hours may be unacceptable whatever the reduction in energy consumption. Retrieving weekly monitoring reports may be very important but difficult to assess a dollar figure.

The greater the number of strategies implemented, the worse the payback for the system. Therefore, each strategy must be well defined and its assumptions thoroughly checked. Only a few will be implemented. The strategy that is implemented may force the use of a networked system.

The number of buildings connected to the system (whether or not they are networked) appears to be more important than the number of points in the system. Rather than invest money in more strategies, spend it on connecting more buildings. The networked system that uses a master control room is a more efficient use of money for systems of a large number of buildings. However, if the money available for the first year is small, the single building controller will probably be used.

The facility operator must commit during the planning process to the manhours and costs of maintaining and operating the system. Unfortunately, little guidance is available.

Escalation of energy costs, assumming they can be reliably projected at all, may affect the size and type of the system. The simple payback ratio seems to be an adequate 'ecision tool.

Installation of direct digital control (DDC) local loops will impact the design of the system.

Quite a few systems are being successfully operated. However, many more have failed to operate satisfactorily or have had serious design or construction problems. Management experience from systems similar to the one developed by the analysis would be useful. Information on a similar network system is probably available due to the wide variety installed, but the information is not easily obtained. Information is unavailable for single building control systems.

Both the network and single building control systems have some solid benefits. Which of the two is selected depends on the type and the amount of control exercised by the facility operator. This requires the facility operator to define the system by concepts, not by hardware.

CHAPTER 11

RECOMMENDATIONS

Although space did not permit a discussion of the process by which the U.S. Navy selects, installs, and operates its systems, research did indicate several areas that merit additional study. Typically, the facility operator, the Public Works Officer (PWO), describes the desired system as a black box and proposes candidate buildings to be connected. Another organization, the Engineering Field Division (EFD), oversees the conceptual studies, design, and construction and turns the completed system back to the PWO. This process takes several years, during which the original concept could be lost or misunderstood.

Since the selection of a system is influenced greatly by how the facility operator will use it, the PWO should have a single manager assigned to coordinate the work of the many persons that will be involved during the life of the system: from conceptual studies; through design and construction; and to the operation and maintenance. The EFD should have an engineer assigned to provide technical assistance and continuity for the systems installed by different Naval Stations.

Establish an office within the Naval Environmental and Energy Support Activity (NEESA) through which facility operators can share experiences. This office should also develop and pass to the operators applications of new techonologies introduced by industry and described by research performed by organizations such as the Naval Civil Engineering Laboratory. Organize a workshop every year or two years for the system managers and engineers to discuss current problems, solutions, and trends.

Remove the current moratorium by the U.S. Navy on new Energy Monitoring and Control Systems.

Perform a sensitivity analysis on the rates of fuel cost escalation and investment value of money. For example, one project may be sensitive to future changes in cost of electricity while another project may be sensitive to the cost of steam. Also, a project that is very sensitive to the rate of inflation may be more of a risk than other investments with similar return.

Study how wind influences the consumption of utilities. In areas experiencing frequent high winds or steady trade winds, infiltration could be a significant heating and cooling load. In such a situation, install a wind direction sensor and wind velocity sensor to the system.

APPENDIX A

ENERGY SAVINGS CALCULATIONS FOR SCENARIO

Excerpted from:

Cornelius, Catherine, Standardized EMCS Energy Savings Calculations, Report 82.030, Naval Civil Engineering Laboratory, Port Hueneme, CA., 93043, September, 1982.

BUILDING DESCRIPTION DATA

BUILDING NUMBER: 500

BUILDING DESCRIPTION: Administration Building

GROSS AREA (SQUARE FEET): 13500 ft² (30' x 150')

NUMBER OF FLOORS: 3

TYPE CONSTRUCTION: Wall: 4" common brick, 1" insulation, 4" conc. block; 20% windows; Roof: builtup with gravel, 2" ins., steel decking, acoustic tile

APPROX. FLOOR TO FLOOR HEIGHT (FT): 12'

GLASS TYPE: Single pane, clear; sliding, aluminum frame

CRITICAL AREAS:

OCCUPANCY SCHEDULE: 730 to 1630, weekdays for majority of building; Frequent weekend occupancy on first floor

SYSTEM DESCRIPTION DATA

BUILDING NUMBER 500

SYS # 1

TYPE Steam/HW Converter

MFGR. MOD. #

CAPACITY

HP (TYPE) ½ hp pump

HP (TYPE)

HP (TYPE)

AREA SERVED 1st floor fan coils

CONTROLS No shutdown at present except for seasonal shutdown

NOTES: Steam from Bldg. 400 - Sys. # 3 boiler

SYS # 2

TYPE Air Cooled Chiller

MFGR. MOD. #

CAPACITY 35 ton

HP (TYPE) 20 hp (each of 2) comp.

HP (TYPE) 5 hp CHW pump

HP (TYPE)

AREA SERVED Sys. # 3, 4, 5

CONTROLS

NOTES: 2 reciprocal compressors

SYS # 3

TYPE Terminal Reheat AHU

MFGR. MOD. #

CAPACITY 3500 cfm (15% OA)

HP (TYPE) 2½ hp supply fan

HP (TYPE)

HP (TYPE)

AREA SERVED 2nd floor - South (3000 ft²)

CONTROLS Existing timeclock, pins have been pulled; pneumatic damper actuators

NOTES: HTHW from heating plant; CHW from Sys #2

SYS # 4

TYPE Variable Air Volume AHU

MFGR. MOD. #

CAPACITY 4000 cfm max (10% OA)

HP (TYPE) 3 hp supply fan

HP (TYPE)

HP (TYPE)

AREA SERVED 3rd floor (4500 ft²)

CONTROLS Existing time clock, set approx. 430 to 1600 weekdays

NOTES: HTHW from heating plant; CHW from Sys. # 2

SYSTEM DESCRIPTION DATA

BUILDING NUMBER 500

SYS # 5	SYS # 6
TYPE Four Pipe Fan Coil Units (15)	TYPE Hot Water Radiation
MFGR. MOD. #	MFGR. MOD. #
CAPACITY	CAPACITY 10 radiators @ 2500 Btu/hr
HP (TYPE) 1/4 hp fan (each)	HP (TYPE) 1/2 hp pump
HP (TYPE)	HP (TYPE)
HP (TYPE)	HP (TYPE)
AREA SERVED First floor (4500 ft²)	AREA SERVED 2nd floor - north (1500 ft²)
CONTROLS Manual shutdown but not very diligent; control valve for htg. & clg. coils at each unit	CONTROLS 3-way bypass valve from heating plant HW loop
NOTES: HW from Sys. #1, CHW from Sys. #2; no OA	NOTES: Area cooled by window units, HTHW from heating plant

SYS #	SYS #
TYPE	TYPE
MFGR. MOD. #	MFGR. MOD. #
CAPACITY	CAPACITY
HP (TYPE)	HP (TYPE)
HP (TYPE)	HP (TYPE)
HP (TYPE)	HP (TYPE)
AREA SERVED	AREA SERVED
CONTROLS	CONTROLS
NOTES:	NOTES:

BUILDING-SPECIFIC FACTORS

BUILDING: 500

* BTT = Building Thermal Transmission

= (U-factor X exterior area) + (Infiltration X 1.08)/Total Floor Area

= (.149 Btu/hr°F-ft²X 17,460 ft²) + (1133 cfm X 1.08)/ 13,500 ft²

= .283 Btu/hr°F-ft²

ERT = Annual Run Time of Equipment for Morning Warmup

Heating Degree Days = 4570 °F-days

Combined U-factor, Uo = .149 Btu/hr°F-ft²

From Figure 9 or 10 : ERT = 220 hr/yr

Primary Sources of Cooling Medium

Sys. No	System Type	Systems Served	CPT
2	AIR COOLED CHILLER	3,4,5	1.18 KW/TON

Primary Sources of Heating Medium

Sys. No	System Type	Systems Served	HEFF	HV
1	STEAM/HW CONVERTER	5	.55**	1031 Btu/cf
BLDG 600-1	HTHW BOILERS (3)	3,4,6	.65(.58**)	138,700 Btu/Gal.

* Data not necessary if computer method is used.

** INCLUDES DISTRIBUTION LOSSES OF PIPING TO AHU'S.

Building 500

Calculation of U-factors:

		$R(ft^2hr°F/Btu)$
Walls: (total = 12,960ft^2)	Outside surface	0.17
	4" common brick	0.433
	8" conc. block	1.11
	1" insulation	9.96
	3/4" gypsum board	0.149
	Inside surface	0.685
		12.507
Windows: (20%)	Outside surface	0.17
	Single pane glass	0.88
	Inside surface	0.685
		1.735
Roof: (4500 ft^2)	Outside surface	0.17
	1/2" slag	0.050
	3/8" membrane	0.285
	2" insulation	13.28
	Steel decking	.0008
	Ceiling tile	1.786
		15.572

$$Uo = \frac{(.80)(12,960)}{(12.507)(17,460)} + \frac{(0.20)(12,960)}{(1.735)(17,460)} + \frac{(4500)}{(15.572)(17,460)}$$

$$= 0.149 \text{ Btu/ft}^2\text{hr°F}$$

Calculation of infiltration:

Walls:

(longest wall)(K)(Fo)(Q/AwKFo) =

$(5400 \text{ ft}^2)(0.66)(.75)(.04)$

= 107 cfm

Windows:

$$\frac{(.20)(12,960ft^2)(20.5 \text{ ft/window})}{(17.5 \text{ ft}^2\text{/window})}(0.3\text{cfm/ft})$$

= 911 cfm

Doors:

(8 doors)(18 ft/door)(0.8 cfm/ft)

= 115 cfm

I = 107 + 911 + 115

= 1133 cfm

CLIMATE - BASED FACTORS

LOCATION: ______________________

SYMBOL	DESCRIPTION	PAGE REF.	VALUE	UNITS
ACWT	Average Condenser Water Temperature	16	75.6	°F
AND	Annual Number of Days for Warmup	18	232	Days/Yr.
AST*	Average Summer Temperature	19	80.6	°F
AWT*	Average Winter Temperature	19	43.0	°F
CFLH	Annual Equiv. Full-Load Hrs. For Cooling	20	733	Hrs/Yr.
HFLH	Annual Equiv. Full-Load Hrs. for Heating	22	538	Hrs/Yr.
HS	Hrs. of Temp. Limit Shut-off for Summer	23	273	Hrs/Yr
HW	Hrs. of Temp. Limit Shut-off for Winter	23	204	Hrs/Yr
OAH*	Average Outside Air Enthalpy	24	33.34	Btu/lb.
PRT*	Percent Run Time for Low Temp. Limit	25	15	%
WKS*	Weeks of Summer	27	23.4	Wks/Yr.
WKW*	Weeks of Winter	27	28.6	Wks/Yr.

* Data not necessary if computer methods are used.

SCHEDULED START/STOP

Clg: BTT x AZ x (80.6°F-78°F) x (168-H) x 23.4 wks/yr x CPT x F/(12,000 Btu/ton-hr)

= 0.00507 x BTT x AZ x (168 - H) x CPT x F

Htg: BTT x AZ x (65°F-55°F) x (168-H) x 28.6 wks/yr x F/(HEFF x HV)

= 286 x BTT x AZ x (168 - H) x F/(HEFF x HV)

V-clg: CFM x POA x (4.5 lb/cfm-hr) x (33.34 - 29.91 Btu/lb) x (168 - H) x 23.4 wks/yr x CPT x F/(12,000 Btu/ton-hr)

= .0301 x CFM x POA x (168-H) x CPT x F

V-htg: CFM x POA x (1.08 Btu/cfm°F-hr) x (65°F-43.0°F) x (168-H) x 28.6 wks/yr x CPT x F/(HEFF x HV)

= 679 x CFM x POA x (168-H) x F/(HEFF x HV)

Aux: HP x 0.8 x (0.746 Kw/hp) x (168-H) x [23.4 wks/yr + (28.6 wk/yr x (1-.15))] x F

= 28.5 x HP x (168-H) x F

DUTY CYCLING

Aux: HP x 0.8 x 10/60 x (.746 Kw/hp) x H x (52 wk/yr)

= 5.17 x HP x H

DEMAND LIMITING

KW: HP x .8 x (0.746 Kw/hp) x 0.25

= 0.149 x HP

OPTIMUM START/STOP

WU Aux: HP x 0.8 x (0.746 Kw/hp) x ((WH x 232) - ERT)
x (DAY/7 day/wk)
= 0.0852 x HP x ((WH x 232) - ERT) x DAY

CD Aux: HP x 0.8 x (0.746 Kw/hp) x (CH-.75 hr/day)
x (365-232 day/yr) x (DAY/7 day/wk)
= 11.3 x HP x (CH-.75) x DAY

OUTSIDE AIR LIMIT SHUTOFF

Aux: HP x 0.8 x (0.746 Kw/hp) x (225 + 164)
= 0.597 x HP x (273 + 204)

VENTILATION AND RECIRCULATION

WU V-htg: CFM x POA x (65° - 43.0°) x (1.08 Btu/cfm°F-hr)
x 232 days/yr x (WH-.25 hr/day)/(HEFF X HV)
= 5512 x CFM x POA x (WH-.25)/(HEFF x HV)

V-clg: CFM x POA x (4.5 lb/cfm-hr) x (33.34-29.91 Btu/lb)
x (UH-(.25 hr/day x DAY)) x 23.4 wks/yr x CPT
/(12,000 Btu/ton-hr)
= 0.0301 x CFM x POA x (UH-.25 x DAY) x CPT

V-htg: CFM x POA x (1.08 Btu/cfm °F-hr) x (65°-43.0°)
x (UH-(.25 hr/day x DAY)) x 28.6 wks/yr/(HEFF x HV)
= 679 x CFM x POA x (UH-.25 x DAY)/(HEFF x HV)

DAY/NIGHT SETBACK

Clg: $\dfrac{\text{BTT x AZ x SU x (168-H) x 23.4 wks/yr x CPT}}{\text{12,000 Btu/ton-hr}}$

= .00195 x BTT x AZ x SU x (168-H) x CPT

Htg: BTT x AZ x SD x (168-H) x 28.6 wks/yr/(HEFF x HV)

= 28.6 x BTT x AZ x SD x (168-H)/(HEFF x HV)

REHEAT COIL RESET

Clg: H x CFM x (4.5 min.lb/hr-ft^3) x (23.4 wks/yr) x RHR x (0.6 Btu/lb) x CPT/(12,000 Btu/Ton-hr)

= .00526 x H x CFM x RHR x CPT

Htg: H x CFM x (1.08 Btu/crm-hr°F) x (52 wk/yr) x RHR/(HEFF x HV)

= 56.16 x H x CFM x RHR/(HEFF x HV)

HOT DECK/COLD DECK TEMPERATURE RESET

Clg: H x CFM x CD x (4.5 min.lb/hr-ft^3) x (23.4 wks/yr) x SCDR x (0.6 Btu/lb) x CPT/(12,000 Btu/Ton-hr)

= .00526 x H x CFM x CD x SCDR x CPT

Htg: H x CFM x HD x (1.08 min.Btu/hr-ft^3°F) x (23.4 x SHDR + 28.6 x WHDR)/(HEFF x HV)

= 1.08 x H x CFM x HD X ((23.4 x SHDR) + (28.6 x WHDR))/(HEFF x HV)

FIGURE 13

PRIMARY SYSTEM

SAVINGS CALCULATIONS AND COSTS

BUILDING NO. ______ SYSTEM NO. _____ SYSTEM TYPE ____________________

FUNCTION	SAVINGS CALCULATIONS	SAVINGS				COST
		KW	KWH		MH	
Scheduled Start/Stop	Clg: * x BTT Btu/ft^2hr °F x AZ ft^2x(168 - H) x F x CPT /ton Htg: * x BTT Btu/ft^2hr °F x AZ ft^2x(168 - H) x F /(HEFFx HV) Aux: * x HP hp x (168 - H) x F					BASIC FUNCTIONS
Duty Cycling	Aux: * x HP hp x H hr					
Demand Limit	KW: * x HP hp					
Optimum Start/Stop	WU Aux: * x HP hp x((WH hr x AND) - ERT hr)x DAY days/wk CD Aux: * x HP hp x (CH hr - .75) x DAY days/wk					
OA Limit	Aux: * x HP hp x (HS + HW)					
Run Time	Labor: 2 Manhours					
HW OA Reset	Htg: HFLH hr/yr x EI x CAP Btu/hr/(HEFFx HV)					
Boiler Opt.	Htg: HFLH hr/yr x EI x CAP Btu/hr/(HEFFx HV)					
Chiller Opt.	Clg: CFLH hr/yr x CPT /ton x TON T x 0.01					
CHW Reset	Clg: CFLH hr/yr x CPT /ton x TON T x REI /°F x 2°F					
Cond. Reset	Clg: CFLH hr/yr x CPT /ton x TON T x (AEI)					
Chiller Demand	Kw: 0.0414 x HP hp					
Safety Alarms	Labor: 2 Manhours					
	TOTALS FOR SYSTEM					

*Derived constants for the specific location.

FIGURE 14
SECONDARY SYSTEM
SAVINGS CALCULATIONS AND COSTS

BUILDING NO. _____ SYSTEM NO. _____ SYSTEM TYPE _____

FUNCTION	SAVINGS CALCULATIONS	SAVINGS KW	SAVINGS KWH	SAVINGS	SAVINGS MH	COST
Scheduled Start/Stop	Clg: * x BTT Btu/ft² hr°F x AZ ft²x(168 - H) x F x CPT /ton Htg: * x BTT Btu/ft²hr°Fx AZ ft²x(168 - H) x F /(HEFF x HV) V-Clg: * x CFM cfm x POA x (168 - H) x F x CPT /ton V-Htg: * x CFM cfm x POA x (168 - H) x F /(HEFF x HV) Aux: * x HP hp x (168 - H) x F					BASIC FUNCTIONS
Duty Cycling	Aux: * x HP hp x H hr					
Demand Limit	KW: * x HP hp					
Optimum Start/Stop	WU Aux: * x HP hp x ((WH hr x AND) - ERT hr)x DAY days/wk CD Aux: * x HP hp x (CH hr - .75) x DAY days/wk					
OA Limit	Aux: * x HP hp x (HS + HW)					
Run Time	Labor: 2 Manhours					
Ventilation/ Recirculation	WU V-htg: * x CFM cfm x POA x (WH -.25)/(HEFF x HV) V-clg: * x CFM cfm x POA x((UH -(.25x DAY dy/wk)) x CPT /ton V-htg: * x CFM cfm x POA x((UH -(.25x DAY dy/wk))/(HEFF x HV)					
Economizer	(Computer simulation required. See page xx).					
Day/Night Setback	Clg: * x BTT Btu/ft²hr°Fx AZ ft²x SU °F x (168 - H) x CPT /ton Htg: * x BTT Btu/ft²hr°Fx AZ ft²x SD °F x (168 - H)/(HEFF x HV)					
Reheat Coil Reset	Clg: * x H hr/wk x CFM cfm x RHR °F x CPT /ton Htg: * x H hr/wk x CFM cfm x RHR °F/(HEFF x HV)					
Hot/Cold Deck Reset	Clg: * x H hr/wk x CFM cfm x CD x SCDR °F x CPT /ton Htg: * x H hr/wk x CFM cfm x HD x(WKS x SHDR x WKW x WHDR)/(HEFF x HV)					
Safety Alarms	Labor: 2 Manhours					
	TOTALS FOR SYSTEM					

*Derived constants for the specific location.

APPENDIX A.3

VARIABLE GLOSSARY

A	=	surface area of tank in ft^2
ACWT	=	average condenser water temperature possible, in °F (See page 16)
AEI	=	adjusted efficiency increase of the chiller due to condenser water reset
AND	=	annual number of days total that warmup is required in days per year (see page 18)
AST	=	average summer temperature in °F (see page 19)
AWT	=	average winter temperature in °F (see page 19)
AZ	=	area of zone being servied in ft^2
BTT	=	building thermal transmission in Btu/hr°F-ft^2 (see page 28)
CAP	=	maximum capacity of device(s) in Btu/hr
CD	=	fraction of total air passing through the cold deck. Assume .50 *if no other* information is available.
CFLH	=	equivalent full-load hours for cooling in hours/year (see page 20)
CFM	=	air handling capacity in ft^3/min
CH	=	present cool-down time before occupancy in hours per day. Use either the actual time presently scheduled for cool-down by an existing timeclock or 2 hours to correspond to Scheduled Start/ Stop savings calculations
CPT	=	energy consumption per ton of refrigeration in kw/ton or lb/ ton-hr (see page 30)
D	=	diameter of tank in ft.
DAY	=	equipment operation in days per week
E	=	parameter determined from Figure 11
EI	=	efficiency increase expressed as a decimal
ERT	=	equipment run time, total required for warm up in hours per year (see page 30)

F	=	fraction of savings attributable to EMCS (see page 42)
H	=	hours of operation per week.
HD	=	fraction of total air passing through the hot deck. Assume .50 if no other information is available.
HEFF	=	heating efficiency of the system (see page 31)
HFLH	=	annual equivalent full load hours for heating in hours/year (see page 22)
HP	=	motor nameplate horsepower
HS	=	hours in summer outside temperature is below summer limit in hours per year (see page 23)
HT	=	height of tank in ft.
HV	=	heating value of fuel in Btu/gal, Btu/kwh etc. (see page 32)
HW	=	hours in winter outside temperature is above winter limit in hours per year (see page 23)
INS	=	thickness of insulation in inches
KW	=	total kw consumption of lights in the zone
L	=	load factor (see page 35)
LSD	=	length of shutdown period in hours
LTL	=	low temperature limit in °F; usually 50°F or 55°F. Use the average winter temperature in place of LTL if AWT > LTL.
NSD	=	number of shutdown periods per year of a given length
OAH	=	average outside air enthalpy in Btu/lb (see page 24)
PCWT	=	present condenser water temperature in °F usually set at 85°F
PEI	=	percent efficiency increase of the chiller
POA	=	present percent minimum outside air expressed as a decimal
PRT	=	percent run time during heating season shutdown period required to maintain a low limit temperature of 55°F (see page 25). Use PRT = 0 if no low temperature limit is planned.

RAH = return air enthalpy. Use 29.91 Btu/lb for 78°F and 50% humidity. For other conditions obtain values from a psychrometric chart.

RCWT = reduction in condenser water temperature which is achievable, in °F

REI = rate of efficiency increase per °F increase of chilled water temperature

RHR = reheat system cooling coil discharge reset in °F. Up to 5° or 6° is possible, dependent on the system. If a better estimate of possible reset is not available use 3°F.

SCDR = summer cold deck reset in °F (the average reset that will result from this function is dependent on the air handler capacity relative to the loads in the space it serves. If an estimate of the possible reset is not available use 3°F)

SD = thermostat setdown for unoccupied periods during the heating season in °F

SHDR = summer hot deck reset in °F (the average reset that will result from this function is dependent on the air handler capacity relative to the loads in the space it serves. If an estimate of the possible reset is not available use 3°F)

SSP = summer thermostat setpoint in °F

SU = thermostat setup for unoccupied periods during the cooling season in °F

T = water temperature at end of shutdown period in °F

To = hot water temperature setpoint in °F

TON = chiller capacity in tons

Ts = average temperature of surroundings in °F

UH = unoccupied hours per week

V = volume of tank in ft^3

WH = present warmup time before occupancy in hours per day

WHDR = winter hot deck reset in °F

WKS = length of summer cooling season in weeks per year (See page 27)

WKW = length of winter heating season in weeks per year (see page 27)

WSP = winter thermostat setpoint in °F

SECONDARY SYSTEM
SAVINGS CALCULATIONS AND COSTS

BUILDING NO. 500 SYSTEM NO. 3 SYSTEM TYPE Terminal Reheat AHU (2)

FUNCTION	SAVINGS CALCULATIONS	SAVINGS KW	SAVINGS KWH	SAVINGS GAL	SAVINGS MH	COST
Scheduled Start/Stop	Clg: .00507 x .283 Btu/ft² hr°F x 3000 ft² x (168 - 55) x .5 x 1.18 /ton Htg: .186 x .283 Btu/ft²hr°F x 3000 ft² x (168 - 55) x .5 /(.58 x 138700) V-Clg: .0301 x 3500 cfm x .15 x (168 - 55) x .5 x 1.18 /ton V-Htg: .679 x 3500 cfm x .15 x (168 - 55) x .5 /(.58 x 138700) Aux: 28.5 x 2.5 hp x (168 - 55) x .5		286 1053 4025	 170.5 250.3		BASIC FUNCTIONS
Duty Cycling	Aux: 5.17 x 2.5 hp x 45 hr		581			
Demand Limit	KW: 0.149 x 2.5 hp	.3				
Optimum Start/Stop	WU Aux: .0852 x 2.5 hp x ((2 hr x 232) - 220 hr) x 5 days/wk CD Aux: 11.3 x 2.5 hp x (2 hr - .75) x 5 days/wk		260 176			
OA Limit	Aux: 0.597 x 2.5 hp x (273 + 204)		712			
Run Time	Labor: 2 Manhours					
Ventilation/ Recirculation	WU V-htg: .5512 x 3500 cfm x .15 x (2 -.25)/(.58 x 138700) V-clg: .0301 x ___ cfm x ___ x((___-(.25x___dy/wk)) x ___ /ton V-htg: .679 x ___ cfm x ___ x((___-(.25x___dy/wk))/(___ x ___)			62.9		
Economizer	(Computer simulation required.)		*			
Day/Night Setback	Clg: .00195 x ___ Btu/ft²hr°F x ___ ft² x ___ °F x (168 - ___) x ___ /ton Htg: 28.6 x ___ Btu/ft²hr°F x ___ ft² x ___ °F x (168 - ___)/(___ x ___)					
Reheat Coil Reset	Clg: .00526 x 50 hr/wk x 3500 cfm x 3 °F x 1.18 kw/ton Htg: 56.16 x 50 hr/wk x 3500 cfm x 3 °F/(.58 x 138,700)		3258	 366.5		
Hot/Cold Deck Reset	Clg: .00526 x ___ hr/wk x ___ cfm x ___ x ___ °F x ___ /ton Htg: 1.08 x ___ hr/wk x ___ cfm x ___ x(___ x ___ + ___ x ___)/(___ x ___)					
Safety Alarms	Labor: 2 Manhours					
	TOTALS FOR SYSTEM	.3	10,351	850.2	0	

*Too small of a system to be economically feasible.

PRIMARY SYSTEM
SAVINGS CALCULATIONS AND COSTS

BUILDING NO. 500 SYSTEM NO. 2 SYSTEM TYPE Air Cooled Chiller (25)

FUNCTION	SAVINGS CALCULATIONS	SAVINGS KW	KWH		MH	COST
Scheduled Start/Stop	*Clg: .00507x ___ Btu/ft²hr °F x ___ ft²x(168 - ___) x ___ x ___ /ton Htg: 286x ___ Btu/ft²hr °F x ___ ft²x(168 - ___) x ___ /(___ x ___) Aux: 28.5 x 5 hp x (168 - 55) x .9		14,492			BASIC FUNCTIONS ___
Duty Cycling	Aux: 5.17 x ___ hp x ___ hr					
Demand Limit	KW: 0.149 x 20 hp (shutting down 1 of 2 compressors)	3.0				
Optimum Start/Stop	WU Aux: .0852 x ___ hp x((___ hr x 232) - ___ hr)x ___ days/wk CD Aux: 11.3 x 5 hp x (2 hr - .75) x 5 days/wk		353			
OA Limit	Aux: 0.597 x 5 hp x (273 + ~~24~~)		815			
Run Time	Labor: 2 Manhours				2	
HW OA Reset	Htg: 538 hr/yr x ___ x ___ Btu/hr/(___ x ___)					___
Boiler Opt.	Htg: 538 hr/yr x ___ x ___ Btu/hr/(___ x ___)					___
Chiller Opt.	Clg: 733 hr/yr x ___ /ton x ___ T x 0.01					___
CHW Reset	Clg: 733 hr/yr x 1.18 kw/ton x 35 T x .012 /°F x 2°F		726			___
Cond. Reset	Clg: 733 hr/yr x ___ /ton x ___ T x (___)					___
Chiller Demand	Kw: 0.0414 x ___ hp					___
Safety Alarms	Labor: 2 Manhours					___
	TOTALS FOR SYSTEM	3.0	16,386	0	2	___

* Cooling and heating savings credited on secondary systems Savings Calculations sheets.

APPENDIX B

RANK STRATEGIES BY COST OF POINTS

ITERATIONS ONE THROUGH SIX

R A N K   S T R A T E G I E S   B Y   E N E R G Y   P A Y B A C K   O N   C O S T   O F   A D D E D   P O I N T S

ITERATION # one

*	POINTS INSTALLED ON AIR HANDLING UNIT															ON CHILLER **							SAVING	COST	PAYBACK	*
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	$/YR	$	***	
A			290													73							$1,561	$363	0.23	A
B	549	600	290													73	162					649	$23	$2,323	101.00	B
C						459	550																$68	$1,009	14.84	C
D	549	600	290			459	550									73	162					649	same as (B) + (C)			D
E						459	550				544												[not]	$1,553		E
F						459	550				544	600											[estim.]	$2,153		F
G			290													73							$40	$363	9.08	G
H	549	600						550	775					544									$540	$3,018	5.59	H
I	549	600								550							162	194					$8	$2,055	256.88	I
J	549		290																				$26	$839	32.27	J
K			290																				$3	$290	96.67	K
L				300			550												78				[no]	$928		L
M	549	600																					[energy]	$1,149		M
N				300				550		550	544		544	544			162		78	70	70		[saved]	$3,412		N
O				300											300					70			[ ]	$670		O

NOTE * : Code letter for Energy Monitoring and Control strategy

NOTE ** : Costs and savings for chiller prorated among air handling units served by the chiller.

NOTE *** : Strategy selected by this iteration is that with the lowest payback

$$\text{PAYBACK} = \frac{\text{(Cost of points that must be installed for strategy)}}{\text{Energy savings for strategy}}$$

——>Strategies selected (installed) from first iteration: A

	SAVING	COST	PAYBACK
CUMULATIVE	1561	363	0.23

(FOR ENERGY SAVING STRATEGIES ONLY!)

RANK STRATEGIES BY ENERGY PAYBACK ON COST OF ADDED POINTS

ITERATION # two The cost of points "installed" during the last iteration are set to zero.

	POINTS INSTALLED ON AIR HANDLING UNIT															ON CHILLER **							SAVING	COST	PAYBACK	
*	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	$/YR	$	***	*
A			290													73							$1,561	$363	0.23	A
B	549	600	0													0	162					649	$23	$1,960	85.22	B
C						459	550																$68	$1,009	14.84	C
D	549	600	0			459	550									0	162					649	same as (B) + (C)			D
E						459	550				544												[not]	$1,553		E
F						459	550				544	600											[estim.]	$2,153		F
G			0													0							$40	$0	0.00	G
H	549	600						550	775					544									$540	$3,018	5.59	H
I	549	600								550							162	194					$8	$2,055	256.88	I
J	549		0																				$26	$549	21.12	J
K			0																				$3	$0	0.00	K
L				300			550												78				[no]	$928		L
M	549	600																					[energy]	$1,149		M
N				300				550		550	544		544	544			162		78	70	70		[saved]	$3,412		N
O				300											300					70			[ ]	$670		O

NOTE * : Code letter for Energy Monitoring and Control strategy

NOTE ** : Costs and savings for chiller prorated among air handling units served by the chiller.

NOTE *** : Strategy selected by this iteration is that with the lowest incremental payback

INCREMENTAL PAYBACK = (Cost of points that must be installed for strategy) - (Cost of those points already installed by previous iterations) / Energy savings for strategy

——>Strategies installed (including this iteration): A G K

	SAVING	COST	PAYBACK
CUMULATIVE	1604	363	0.23

(FOR ENERGY SAVING STRATEGIES ONLY!)

RANK STRATEGIES BY ENERGY PAYBACK ON COST OF ADDED POINTS

ITERATION # three   The cost of points "installed" during the last iteration are set to zero.

*	POINTS INSTALLED ON AIR HANDLING UNIT															ON CHILLER **							SAVING	COST	PAYBACK	*
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	$/YR	$	***	
A			290													73							$1,561	$363	0.23	A
B	0	0	0													0	162					649	$23	$811	35.26	B
C						459	550																$68	$1,009	14.84	C
D	0	0	0			459	550									0	162					649	same as (B) + (C)			D
E						459	550				544												[not]	$1,553		E
F						459	550				544	600											[estim.]	$2,153		F
G			0													0							$40	$0	0.00	G
H	549	600						550	775					544									$540	$3,018	5.59	H
I	0	0								550							162	194					$8	$906	113.25	I
J	0		0																				$26	$0	0.00	J
K			0																				$3	$0	0.00	K
L				300			550												78				[no]	$928		L
M	0	0																					[energy]	$0		M
N				300				0		550	544		544	0			162		78	70	70		[saved]	$2,318		N
O				300											300					70			[ ]	$670		O

NOTE * : Code letter for Energy Monitoring and Control strategy

NOTE ** : Costs and savings for chiller prorated among air handling units served by the chiller.

NOTE *** : Strategy selected by this iteration is that with the lowest incremental payback

$$\text{INCREMENTAL PAYBACK} = \frac{\text{(Cost of points that must be installed for strategy)} - \text{(Cost of those points already installed by previous iterations)}}{\text{Energy savings for strategy}}$$

——>Strategies installed (including this iteration): A G K H

	SAVING	COST	PAYBACK
CUMULATIVE	2144	3381	1.58

(FOR ENERGY SAVING STRATEGIES ONLY!)

RANK STRATEGIES BY ENERGY PAYBACK ON COST OF ADDED POINTS

ITERATION # four   The cost of points "installed" during the last iteration are set to zero.

*	POINTS INSTALLED ON AIR HANDLING UNIT 6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	ON CHILLER ** 21	22	23	24	25	26	27	SAVING $/YR	COST $	PAYBACK ***	*
A			290													73							$1,561	$363	0.23	A
B	0	0	0													0	162					649	$23	$811	35.26	B
C						459	550																$68	$1,009	14.84	C
D	0	0	0			0	0									0	162					649	same as (B) + (C)			D
E						0	0				544												[not]	$544		E
F						0	0				544	600											[estim.]	$1,144		F
G			0													0							$40	$0	0.00	G
H	549	600						550	775					544									$540	$3,018	5.59	H
I	0	0								550							162	194					$8	$906	113.25	I
J	0		0																				$26	$0	0.00	J
K			0																				$3	$0	0.00	K
L				300			0												78				[no]	$378		L
M	0	0																					[energy]	$0		M
N				300				0		550	544		544	0			162		78	70	70		[saved]	$2,318		N
O				300											300					70			[ ]	$670		O

NOTE * : Code letter for Energy Monitoring and Control strategy

NOTE ** : Costs and savings for chiller prorated among air handling units served by the chiller.

NOTE *** : Strategy selected by this iteration is that with the lowest incremental payback

$$\text{INCREMENTAL PAYBACK} = \frac{\text{(Cost of points that must be installed for strategy)} - \text{(Cost of those points already installed by previous iterations)}}{\text{Energy savings for strategy}}$$

——>Strategies installed (including this iteration): A G K H J C

	SAVING	COST	PAYBACK
CUMULATIVE	2238	4390	1.96

(FOR ENERGY SAVING STRATEGIES ONLY!)

RANK STRATEGIES BY ENERGY PAYBACK ON COST OF ADDED POINTS

ITERATION # five   The cost of points "installed" during the last iteration are set to zero.

*	POINTS INSTALLED ON AIR HANDLING UNIT 6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	ON CHILLER ** 21	22	23	24	25	26	27	SAVING $/YR	COST $	PAYBACK ***	*
A			290													73							$1,561	$363	0.23	A
B	0	0	0													0	162					649	$23	$811	35.26	B
C						459	550																$68	$1,009	14.84	C
D	0	0	0			0	0									0	0					0	same as (B) + (C)			D
E						0	0				544												[not]	$544		E
F						0	0				544	600											[estim.]	$1,144		F
G			0													0							$40	$0	0.00	G
H	549	600						550	775					544									$540	$3,018	5.59	H
I	0	0								550							0	194					$8	$744	93.00	I
J	0		0																				$26	$0	0.00	J
K			0																				$3	$0	0.00	K
L				300			0												78				[no]	$378		L
M	0	0																					[energy]	$0		M
N				300				0		550	544		544	0			0		78	70	70		[saved]	$2,156		N
O				300											300					70			[ ]	$670		O

NOTE * : Code letter for Energy Monitoring and Control strategy

NOTE ** : Costs and savings for chiller prorated among air handling units served by the chiller.

NOTE *** : Strategy selected by this iteration is that with the lowest incremental payback

$$\text{INCREMENTAL PAYBACK} = \frac{\text{(Cost of points that must be installed for strategy) - (Cost of those points already installed by previous iterations)}}{\text{Energy savings for strategy}}$$

——>Strategies installed (including this iteration): A G K H J C B

	SAVING	COST	PAYBACK
CUMULATIVE	2261	5201	2.30

(FOR ENERGY SAVING STRATEGIES ONLY!)

RANK STRATEGIES BY ENERGY PAYBACK ON COST OF ADDED POINTS

ITERATION # six   The cost of points "installed" during the last iteration are set to zero.

	POINTS INSTALLED ON AIR HANDLING UNIT															ON CHILLER **							SAVING	COST	PAYBACK	
*	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	$/YR	$	***	*
A			290													73							$1,561	$363	0.23	A
B	0	0	0													0	162					649	$23	$811	35.26	B
C						459	550																$68	$1,009	14.84	C
D	0	0	0			0	0									0	0					0	same as (B) + (C)			D
E						0	0				544												[not]	$544		E
F						0	0				544	600											[estim.]	$1,144		F
G			0													0							$40	$0	0.00	G
H	549	600						550	775					544									$540	$3,018	5.59	H
I	0	0								550							0	194					$8	$744	93.00	I
J	0		0																				$26	$0	0.00	J
K			0																				$3	$0	0.00	K
L				300			0												78				[no]	$378		L
M	0	0																					[energy]	$0		M
N				300				0		0	544		544	0			0		78	70	70		[saved]	$1,606		N
O				300											300					70			[ ]	$670		O

NOTE * : Code letter for Energy Monitoring and Control strategy

NOTE ** : Costs and savings for chiller prorated among air handling units served by the chiller.

NOTE *** : Strategy selected by this iteration is that with the lowest incremental payback

$$\text{INCREMENTAL PAYBACK} = \frac{\text{(Cost of points that must be installed for strategy) - (Cost of those points already installed by previous iterations)}}{\text{Energy savings for strategy}}$$

——>Strategies installed (including this iteration): A G K H J C B I

	SAVING	COST	PAYBACK
CUMULATIVE	2269	5945	2.62

(FOR ENERGY SAVING STRATEGIES ONLY!)

APPENDIX C

SYSTEM COST AND PAYBACK WORKSHEETS

APPENDIX C

COSTS AND PAYBACKS FOR DIFFERENT COMBINATIONS

Three air handling units (AHU's) in each building

1	Combination number		1	2	3
2	Strategies implemented		A	A	A+G+K
3	Point cost for one AHU		$363	$363	$363
4	Building point cost		$1,162	$1,162	$1,162
5	Number of points per AHU		1	1	1
6	Number of points on chiller		1	1	1
7	Additional	AHU	0	0	0
8	points per	Chiller	0	0	0
9	building	Other	0	0	0
10	Total # points per building		4	4	4
11	# buildings for 240-260 pts		60	60	60
12	# buildings (alternatives)				
13	Building	Type	F	J	F
14	loops	Cost each	$4,003	$8,800	$4,003
15	Cost for all building loops		$240,180	$528,000	$240,180
16	System	number	0	0	2
17	points	total cost	$0	$0	$2,253
18		Type	A	E	A
19	System	Hardware	$48,530	$0	$48,530
20	costs	Software	$33,000	$0	$33,000
21		Construction	$15,850	$1,980	$15,860
22		Start-up	$37,280	$19,480	$37,434
23	Total initial cost		$444,560	$619,185	$446,977
24	Total number of points		240	240	242
25	Cost per point (average)		$1,852	$2,580	$1,847
26	Energy reductions per AHU		$1,561	$1,561	$1,604
27	Total energy reduction		$374,640	$374,640	$384,960
28	O & M reduction/(increase)		$0	$0	$0
29	SIMPLE PAYBACK		1.19	1.65	1.16
30	Cost per building		$7,409	$10,320	$7,450

APPENDIX C

COSTS AND PAYBACKS FOR DIFFERENT COMBINATIONS

Three air handling units (AHU's) in each building

1	Combination number		4	5	6
2	Strategies implemented		A+G+H	A+G+H	A+G+H
3	Point cost for one AHU		$3,381	$3,381	$3,381
4	Building point cost		$10,216	$10,216	$10,765
5	Number of points per AHU		6	6	6
6	Number of points on chiller		1	1	1
7	Additional	AHU	0	0	0
8	points per	Chiller	0	0	0
9	building	Other	0	0	1
10	Total # points per building		19	19	20
11	# buildings for 240-260 pts		13	13	13
12	# buildings (alternatives)				
13	Building	Type	F	F	J
14	loops	Cost each	$4,003	$4,003	$8,800
15	Cost for all building loops		$52,039	$52,039	$114,400
16	System	number	1	1	0
17	points	total cost	$549	$549	$0
18		Type	A	B	E
19	System	Hardware	$48,530	$54,030	$0
20	costs	Software	$33,000	$33,000	$0
21		Construction	$15,890	$15,890	$2,020
22		Start-up	$37,896	$41,796	$21,020
23	Total initial cost		$320,712	$330,112	$277,385
24	Total number of points		248	248	260
25	Cost per point (average)		$1,293	$1,331	$1,067
26	Energy reductions per AHU		$2,141	$2,141	$2,141
27	Total energy reduction		$111,332	$111,332	$111,332
28	O & M reduction/(increase)		$0	$0	$0
29	SIMPLE PAYBACK		2.88	2.97	2.49
30	Cost per building		$24,670	$25,393	$21,337

APPENDIX C

COSTS AND PAYBACKS FOR DIFFERENT COMBINATIONS

Three air handling units (AHU's) in each building

1	Combination number		7	8	9
2	Strategies implemented		A+M	A+M	A+G+H+M
3	Point cost for one AHU		$363	$363	$3,381
4	Building point cost		$4,497	$4,497	$13,634
5	Number of points per AHU		1	1	6
6	Number of points on chiller		1	1	1
7	Additional	AHU	0	0	0
8	points per	Chiller	0	0	0
9	building	Other	2	2	2
10	Total # points per building		6	6	21
11	# buildings for 240-260 pts			40	
12	# buildings (alternatives)		60		60
13	Building	Type	F	F	F
14	loops	Cost each	$4,003	$4,003	$4,003
15	Cost for all building loops		$240,180	$160,120	$240,180
16	System	number	2	2	2
17	points	total cost	$1,149	$1,149	$1,149
18		Type	A	A	A
19	System	Hardware	$48,530	$48,530	$48,530
20	costs	Software	$33,000	$33,000	$33,000
21		Construction	$16,460	$25,860	$20,960
22		Start-up	$46,674	$37,434	$115,974
23	Total initial cost		$655,813	$475,973	$1,277,233
24	Total number of points		362	242	1262
25	Cost per point (average)		$1,811	$1,967	$1,012
26	Energy reductions per AHU		$1,561	$1,561	$2,141
27	Total energy reduction		$374,640	$249,760	$513,840
28	O & M reduction/(increase)		$3,120	$2,080	$3,120
29	SIMPLE PAYBACK		1.74	1.89	2.47
30	Cost per building		$10,930	$11,899	$21,287

APPENDIX C

COSTS AND PAYBACKS FOR DIFFERENT COMBINATIONS

Three air handling units (AHU's) in each building

1	Combination number		10	11	12
2	Strategies implemented		A+G+H+M	A+G+H+M	A+M
3	Point cost for one AHU		$3,381	$3,381	$363
4	Building point cost		$13,634	$13,634	$4,497
5	Number of points per AHU		6	6	1
6	Number of points on chiller		1	1	1
7	Additional	AHU	0	0	0
8	points per	Chiller	0	0	0
9	building	Other	2	2	2
10	Total # points per building		21	21	6
11	# buildings for 240-260 pts			12	
12	# buildings (alternatives)		13		60
13	Building	Type	F	F	J
14	loops	Cost each	$4,003	$4,003	$8,800
15	Cost for all building loops		$52,039	$48,036	$528,000
16	System	number	2	2	2
17	points	total cost	$1,149	$1,149	$1,149
18		Type	A	A	E
19	System	Hardware	$48,530	$48,530	$0
20	costs	Software	$33,000	$33,000	$0
21		Construction	$16,025	$15,920	$2,224
22		Start-up	$39,975	$38,538	$28,874
23	Total initial cost		$367,830	$348,481	$830,067
24	Total number of points		275	254	362
25	Cost per point (average)		$1,338	$1,372	$2,293
26	Energy reductions per AHU		$2,141	$2,141	$1,561
27	Total energy reduction		$111,332	$102,768	$374,640
28	O & M reduction/(increase)		$676	$624	($6,000)
29	SIMPLE PAYBACK		3.28	3.37	2.25
30	Cost per building		$28,295	$29,040	$13,834

APPENDIX C

COSTS AND PAYBACKS FOR DIFFERENT COMBINATIONS

Three air handling units (AHU's) in each building

1	Combination number		13	14	15
2	Strategies implemented		A+M	A+G+H+M	A+G+H+M
3	Point cost for one AHU		$363	$3,381	$3,381
4	Building point cost		$4,497	$14,173	$14,173
5	Number of points per AHU		1	6	6
6	Number of points on chiller		1	1	1
7	Additional	AHU	0	0	0
8	points per	Chiller	0	0	0
9	building	Other	2	3	3
10	Total # points per building		6	22	22
11	# buildings for 240-260 pts		40		
12	# buildings (alternatives)			60	13
13	Building	Type	J	J	J
14	loops	Cost each	$8,800	$8,800	$8,800
15	Cost for all building loops		$352,000	$528,000	$114,400
16	System	number	2	1	1
17	points	total cost	$1,149	$600	$600
18		Type	E	E	E
19	System	Hardware	$0	$0	$0
20	costs	Software	$0	$0	$0
21		Construction	$1,984	$4,142	$2,074
22		Start-up	$19,634	$102,717	$23,099
23	Total initial cost		$554,647	$1,405,839	$324,422
24	Total number of points		242	1321	287
25	Cost per point (average)		$2,292	$1,125	$1,130
26	Energy reductions per AHU		$1,561	$2,141	$2,141
27	Total energy reduction		$249,760	$513,840	$111,332
28	O & M reduction/(increase)		($4,000)	($6,000)	($1,300)
29	SIMPLE PAYBACK		2.25	2.93	2.95
30	Cost per building		$13,866	$24,764	$24,956

APPENDIX C

COSTS AND PAYBACKS FOR DIFFERENT COMBINATIONS

Three air handling units (AHU's) in each building

1	Combination number		16	17	18
2	Strategies implemented		A+G+H+M	A+G+H	A+G+H
3	Point cost for one AHU		$3,381	$3,381	$3,381
4	Building point cost		$14,173	$10,216	$10,765
5	Number of points per AHU		6	6	6
6	Number of points on chiller		1	1	1
7	Additional	AHU	0	0	0
8	points per	Chiller	0	0	0
9	building	Other	3	0	1
10	Total # points per building		22	19	20
11	# buildings for 240-260 pts		12		
12	# buildings (alternatives)			60	60
13	Building	Type	J	F	J
14	loops	Cost each	$8,800	$4,003	$8,800
15	Cost for all building loops		$105,600	$240,180	$528,000
16	System	number	1	1	0
17	points	total cost	$600	$549	$0
18		Type	E	A	E
19	System	Hardware	$0	$48,530	$0
20	costs	Software	$0	$33,000	$0
21		Construction	$2,030	$20,355	$3,900
22		Start-up	$21,405	$106,657	$93,400
23	Total initial cost		$299,711	1,062,231	1,271,200
24	Total number of points		265	1141	1200
25	Cost per point (average)		$1,131	$931	$1,059
26	Energy reductions per AHU		$2,141	$2,141	$2,141
27	Total energy reduction		$102,768	$513,840	$513,840
28	O & M reduction/(increase)		($1,200)	$0	$0
29	SIMPLE PAYBACK		2.95	2.07	2.47
30	Cost per building		$24,976	$17,704	$21,187

APPENDIX C

COSTS AND PAYBACKS FOR DIFFERENT COMBINATIONS

Three air handling units (AHU's) in each building

1	Combination number		19	20	21
2	Strategies implemented		A	A	A+M
3	Point cost for one AHU		$363	$363	$363
4	Building point cost		$1,162	$1,162	$4,497
5	Number of points per AHU		1	1	1
6	Number of points on chiller		1	1	1
7	Additional	AHU	0	0	0
8	points per	Chiller	0	0	0
9	building	Other	0	0	2
10	Total # points per building		4	4	6
11	# buildings for 240-260 pts				
12	# buildings (alternatives)		13	13	13
13	Building	Type	F	J	F
14	loops	Cost each	$4,003	$8,800	$4,003
15	Cost for all building loops		$52,039	$114,400	$52,039
16	System	number	0	0	2
17	points	total cost	$0	$0	$1,149
18		Type	A	E	A
19	System	Hardware	$48,530	$0	$48,530
20	costs	Software	$33,000	$0	$33,000
21		Construction	$14,910	$1,604	$15,050
22		Start-up	$22,804	$4,104	$24,960
23	Total initial cost		$186,389	$135,214	$233,189
24	Total number of points		52	52	80
25	Cost per point (average)		$3,584	$2,600	$2,915
26	Energy reductions per AHU		$1,561	$1,561	$1,561
27	Total energy reduction		$81,172	$81,172	$81,172
28	O & M reduction/(increase)		$0	$0	$676
29	SIMPLE PAYBACK		2.30	1.67	2.85
30	Cost per building		$14,338	$10,401	$17,938

APPENDIX C

COSTS AND PAYBACKS FOR DIFFERENT COMBINATIONS

Three air handling units (AHU's) in each building

1	Combination number		22	23	24
2	Strategies implemented		A+M	A+G+H	A+G+H
3	Point cost for one AHU		$363	$3,381	$3,381
4	Building point cost		$4,497	$10,216	$10,765
5	Number of points per AHU		1	6	6
6	Number of points on chiller		1	1	1
7	Additional	AHU	0	0	0
8	points per	Chiller	0	0	0
9	building	Other	2	0	1
10	Total # points per building		6	19	20
11	# buildings for 240-260 pts				
12	# buildings (alternatives)		13	40	40
13	Building	Type	J	F	J
14	loops	Cost each	$8,800	$4,003	$8,800
15	Cost for all building loops		$114,400	$160,120	$352,000
16	System	number	2	1	0
17	points	total cost	$1,149	$549	$0
18		Type	E	A	E
19	System	Hardware	$0	$48,530	$0
20	costs	Software	$0	$33,000	$0
21		Construction	$1,660	$18,455	$3,100
22		Start-up	$7,160	$77,397	$62,600
23	Total initial cost		$182,830	$746,691	$848,300
24	Total number of points		80	761	800
25	Cost per point (average)		$2,285	$981	$1,060
26	Energy reductions per AHU		$1,561	$2,141	$2,141
27	Total energy reduction		$81,172	$342,560	$342,560
28	O & M reduction/(increase)		($1,300)	$0	$0
29	SIMPLE PAYBACK		2.29	2.18	2.48
30	Cost per building		$14,064	$18,667	$21,208

REFERENCES

REFERENCES

1. Alchian, Allen A., and Thomas J. Burns, Energy Monitoring and Control Systems Effectiveness and Efficiency, Thesis, LSSR-7-78B, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, September, 1978

2. "Annual Energy Techonology Buyers' Guide", Energy User News, Fairchild Publications, 7 E. 12th St., New York, N.Y.,10003, December 31,1984.

3. Baker, David W., and C. Warren Hurley, On-Site Calibration of Flow Metering Systems Installed in Buildings, Building Science Series 159, Center for Building Technology, National Bureau of Standards, Washington, D.C., 20234, January, 1984.

4. Bosh & LaTour, Engineers--Consultants, Manual for Selection, Application, and Cost Analysis of Central Building Automation Systems, Naval Facilities Engineering Command, 200 Stoval St., Alexandria, VA.,22332, April, 1975.

5. Bruning, Steve, EMCS Installation Follow-Up Study, Vol I and II, Report CR 84.024, Naval Civil Engineering Laboratory, Port Hueneme, CA., March 1984.

6. Cornelius, Catherine, EMCS Cost Estimating Guide, Report CR 83.008, Naval Civil Engineering Laboratory, Port Hueneme, CA., 93043, January, 1983.

7. Cornelius, Catherine, Standardized EMCS Energy Saving Calculations, Report CR 82.030, Naval Civil Engineering Laboratory, Port Hueneme, CA., 93043, September, 1982.

8. Cornelius, Catherine, and Billy Wise, Energy Monitoring and Control Systems Operator Training -- Recommended Qualifications, Staffing, Job Description, and Training Requirements for EMCS Operators, Report 82.027, Naval Civil Engineering Laboratory, Port Hueneme, CA., 93043, June, 1982.

9. Cornelius, Catherine, Billy Wise, and Steven Bruning, EMCS Operator Training Manual, Report 83.021, Naval Civil Engineering Laboratory, Port Hueneme, CA., 93043, April, 1983.

10. EMC Engineers, Inc., Investigation of Microprocessor Based Equipment Maintenance, Preliminary Report, unpublished, Naval Civil Engineering Laboratory, Port Hueneme, CA, 93043, April, 1984.

11. Energy Conservation With Comfort, 2ed., Honeywell, Inc., Minneapolis, Minn., 55408, date unknown.

12. Energy Management Systems Sourcebook, edited by Albert Thumann, The Fairmont Press, P.O. Box 14227, Atlanta, GA., 30324, 1985.

13. Energy Monitoring and Control Systems, Design Manual 4.9, DM 4.9, Naval Facilities Engineering Command, 200 Stovall Street, Alexandria, Virginia, 22332, September, 1983.

14. "Energy Price Changes: August 1970 to August 1985", Energy User News, Fairchild Publications, 7 E. 12th St., New York, N.Y., 10003, September 30, 1985.

15. "Circuit Board Allows IBM to Perform DDC", Energy User News, Fairchild Publications, 7 E. 12th St., New York, N.Y., 10003, July 29, 1985.

16. Hittle, Douglas C., and David L. Johnson, New Control Design Principles Based on Measured Performance and Energy Analysis of HVAC Systems, Interim Report E-85/02, U.S. Army Construction Engineering Research Laboratory, P.O. Box 4005, Champain, IL, 61820, January 1985.

17. Hittle, Douglas C., and David L. Johnson, Summary of USA-CERL Research on Control of Heating, Ventilating, and Air Conditioning Systems, Special Report E-197, U.S. Army Construction Engineering Research Laboratory, P.O. Box 4005, Champain, IL, 61820, July, 1984.

18. Hurley, C. Warren, and James S. Schooley, Calibration of Temperature Measurement Systems Installed in Buildings, Building Science Series 153, National Bureau of Standards, Washington, D.C., 20234, January, 1984

19. Ingraham, Rob, "Westinghouse Unveils Its First Commercial, Institutional EMS", Energy User News, Fairchild Publications, 7 E. 12th St., New York, N.Y., 10003, September 9, 1985.

20. Kao, James Y., and David W. Baker, A Commentary on the Instrumentation For Building Energy Monitoring and Control Systems (EMCS), NBSIR 80-2104, Center for Building Technology, National Bureau of Standards, Washington, D.C., 20234, September, 1980.

21. Kirts, R. E., Control Strategies for Reducing Heating, Ventilating, and Air Conditioning (HVAC) Energy Consumption in Single Buildings, Technical Note 1658, Naval Civil Engineering Laboratory, Port Hueneme, California, 93043, March, 1983.

22. Kirts, R. E.,Users Guide to Direct Digital Control of Heating, Ventilating, and Air Conditioning Equipment, UG-0004, Naval Civil Engineering Laboratory, Port Hueneme, California, 93043, January, 1985

23. Kling-Lindquist, Inc., Energy Monitoring and Control Systems Factory Test Procedures, Report CR 83.002, Naval Civil Engineering Laboratory, Port Hueneme, CA, 93043, December, 1982.

24. Kling-Lindquist, Inc., Energy Monitoring and Control Systems Inspection Guidelines, Report CR 83.001, Naval Civil Engineering Laboratory, Port Hueneme, CA, 93043, December, 1982.

25. Kling-Lindquist, Inc., Energy Monitoring and Control Systems -- Performance Verification and Endurance Test Procedures, Report CR 83.003, Naval Civil Engineering Laboratory, Port Hueneme, CA, 93043, December, 1982.

26. Mace, Jerry, maintenance procedures, private communication with author, Norfolk Naval Shipyard, Portsmouth, VA, 23709, May, 1985.

27. Maintenance of Computerized Automation Systems, Contract N62477-84-B-1015, United States Naval Academy, Annapolis, Maryland, 21402, June, 1985.

28. Neipp, Bill, repairs to existing controls, personal communication with author, Naval Air Station Miramar, San Diego, CA, 92148, June, 1985.

29. Operation and Maintenance of Energy Monitoring and Control System, Contract N62470-82-C-2461, Camp Lejeune, North Carolina, September, September, 1982.

30. Patrick, Dale R., and Stephen W. Fardo, Energy Management and Conservation, Prentice-Hall, Inc., Englewood Cliffs, N.J., 07632, 1982.

31. Payne, William F., Energy Management and Control Systems Handbook, The Fairmont Press, Inc., P.O. Box 14227, Atlanta, GA., 30324, 1984.

32. Ponczak, Glen, "Merits of Front-End Computors Debated for Mid-Size EMS", Energy User News, Fairchild Publications, 7 E 12th St., New York, N.Y., 10003, October 14, 1985.

33. Rees, Jeff, Controlling Energy Consumption in Single Buildings, Report CR 82.028, Naval Civil Engineering Laboratory, Port Hueneme, CA., 93043, July, 1982.

34. Sanchez, Ivan, John Franchi, and Karlin Canfield, Evaluation of a Commercially Available Single Building EMCS (SBEMCS), Report TR-914, Naval Civil Engineering Laboratory, Port Hueneme, CA., 93043, February, 1985.

35. Schultz, Robert J., Thomas M. Kenna, and Larraine A. Kapka, An Investigation into the Operation and Maintenance of Heating, Ventilating, and Air Conditioning Systems in the United States Air Force, School of Civil Engineering, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, 45433, 18 November, 1982.

36. Selecting an Energy Controller for your Building, Techdata Sheet 82-02, Naval Civil Engineering Laboratory, Port Hueneme, CA., February, 1982.

37. Springer, Neil, "Clinic Expands Distributed EMS to 6 Buildings", Energy User News, Fairchild Publications, 7 E 12th St., New York, N.Y., 10003, May 27, 1985.

38. Stan, Robert, Selection and Implementation of Single Building EMCS, Report 83.037, Naval Civil Engineering Laboratory, Port Hueneme, CA., 93043, August, 1983.

39. Sura, Jim, "Point Maintenance Listing", personal communication with author, Puget Sound Naval Shipyard, Bremerton, WA., 98314, June, 1985.

40. Waste Watchers Guide, Naval Facilities Engineering Command, 200 Stovall Street, Alexandria, VA., 22332, (compilation of many reports on energy conservation topics), no date.

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